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SUMMARY AND ASSESSMENT OF PUBLISHED INFORMATION ON DETERMINING LEAD EXPOSURES AND MITIGATING LEAD HAZARDS ASSOCIATED WITH DUST AND SOIL IN RESIDENTIAL CARPETS, FURNITURE, AND FORCED AIR DUCTS

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CONTRIBUTING ORGANIZATIONS

This report presents the results of studies which have measured the extent of lead exposure associated with carpets, furniture, and forced air ducts, and/or which have investigated methods of mitigating such lead exposures. Efforts to produce this report were funded and managed by the U.S. Environmental Protection Agency. The report was prepared by Battelle under contract to the U.S. Environmental Protection Agency. Each organization's responsibilities are listed below.

Battelle Memorial Institute (Battelle)

Battelle was responsible for conducting literature searches on this subject, procuring relevant articles and reports, reviewing these publications, and preparing the report.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency was responsible for providing report objectives, for contributing relevant information for the report, for reviewing the report, and for arranging the peer review of the report. The EPA Work Assignment Manager was Dr. Benjamin S. Lim. The EPA Project Officer was Sineta Wooten.

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EXECUTIVE SUMMARY

This report presents the findings of a literature review on information concerning lead in dust within residential carpets, furniture (including upholstery and window treatments), and forced air ducts. Research areas include: 1) determining amounts of lead in dust within these surfaces (including dust collection techniques), 2) characterizing the association between lead contamination of dust within these surfaces and children's blood-lead concentration, and 3) mitigating lead-contaminated dust within these surfaces that pose a potential lead exposure to residents, especially children. This review is in support of research by the U.S. Environmental Protection Agency (EPA) in their efforts to address Congressional mandates within Title X (specifically, Section 1051).

While 59 documents provided information on dust and lead exposure associated with residential carpet, only 11 documents provided information relative to residential furniture, upholstery, and window treatments, and only eight documents provided information relative to residential air ducts. This information was typically a small part of the total information presented in these documents and was often insufficient to answer the questions addressed in this report. In addition, the studies referenced in these documents did not necessarily address the specific objectives of this report. Therefore, considerable research is necessary to adequately characterize lead exposures associated with these lead sources, as well as to mitigate such exposures.

Among the main findings of the literature review are the following (according to lead source):

Carpets

! Over time, carpets can become a reservoir of dust and exterior soil introduced to a residence.

! Different methods used to collect dust from carpets (and other surfaces) may collect different types of dust, thereby affecting how dust-lead is characterized.

! As carpets can hold large amounts of dust and soil and provide less particle movement relative to hard surfaces, carpet dust-lead loading can be high, while dust-lead concentration tends to be low except in high-traffic areas.

! Carpets that are easily able to trap dust within their fibers, such as clean carpets, may act as a short-term mitigator of lead exposure associated with floor dust.

! Behavioral techniques that limit the amount of exterior contamination, such as removing shoes prior to entry and use of walk-off mats, have been found to significantly reduce the likelihood of lead contamination of carpets.

- When sampling dust from carpets, factors significantly associated with reduced collection efficiency from vacuum methods include shag carpets, low relative humidity, low vacuum particle lifting velocity, fine dust particles, and no agitator bar present on the vacuum.

- Lead levels in carpet dust tend to have a significant positive association with children's blood-lead concentration, with dust-lead loading having a higher correlation than dust-lead concentration.

- Repeated vacuuming of old, contaminated carpets may increase lead-loading in surface dust if deeply-embedded dust cannot be removed in its entirety. For such carpets, it may be better to remove them than to decontaminate them. Carpet removal may be preferable if the carpet is a shag carpet, or if it has been highly contaminated by remodeling, peeling paint, paint removal, or being near a lead source, such as a lead or copper smelter, secondary smelter, etc.

- Use of wet methods to decontaminate carpets was generally found to be ineffective. However, use of detergent-based solutions that reduce the electrostatic interaction between carpet and lead-dust (such as sodium hexa-metaphosphate solutions, whose phosphate or polyphosphate groups coat the dust particles) has been effective, reducing dust-lead concentrations on average from 30% to 50% and dust-lead loadings by 60%.

- Effective cleaning of carpets, furniture, bare floors, and bare surfaces has been documented to reduce lead exposure in the home. A plush carpet is more popular than level loop or flat carpets, yet they are more difficult to clean. Old shag rugs are the hardest type of carpet to clean effectively.

Furniture

- While the same dust collection methods tend to be used to sample dust from carpets and furniture, one method (the High Volume Furniture Sampler, a modification of the HVS3) was developed specifically for sampling dust from upholstered surfaces. However, no field study has been encountered which used this dust sampler.

- Average dust-lead loadings on furniture, upholstery, and window treatments are generally lower than for other surfaces, such as floors, windows, and air ducts.

- A significantly positive correlation coefficient between blood-lead concentration and (pre-intervention) dust-lead levels in upholstery was observed within the Baltimore R&M study. However, positive correlation coefficients imply only statistical association, and not a causal relationship.

- Foreign-made, vinyl mini-blinds can be a direct source of dust-lead, as documented by the Consumer Product Safety Commission (CPSC).

- While several procedures were used to mitigate dust-lead in furniture, upholstery, and window treatments, available data were limited and inconclusive.

Air Ducts

- Lead loadings in air ducts are generally very high, especially when the ducts contain large amounts of dust, or when ductwork is old.

- It is not certain how lead in air ducts may be bioavailable to humans, especially in the absence of renovation or cleaning.

- One study reported that, on average, lead in dust within air ducts represented nearly one-third of lead in household dust (only floor-dust represented more).

- In the Baltimore R&M study, the correlation coefficient between blood-lead concentration and (pre-intervention) dust-lead levels in air ducts was not significant at the 0.05 level. However, this analysis was based on a small sample size and did not adjust for the effects of other exposure variables such as lead in floor dust and soil. Lead levels in air ducts were found to be significantly correlated with lead levels on certain surfaces, such as floors.

- While one study detailed a protocol used to mitigate dust in air ducts, available data to evaluate mitigation procedures were virtually non-existent.

1.0 INTRODUCTION

Lead poisoning is recognized as a pervasive, yet preventable, environmental health problem in this country. While some humans become exposed to lead by coming into direct contact with a lead source (e.g., ingesting lead-based paint chips), many others become exposed to lead by contact with environmental media that indirectly become lead-contaminated. In particular, if dust on surfaces which are accessible to children has become lead-contaminated by sources such as lead-based paint and lead-contaminated soil, then children can become exposed to lead by encountering this dust.

On October 29, 1992, the President of the United States signed into law the Residential Lead-Based Paint Hazard Reduction Act (Title X of HR 5334). Section 1051 of Title X gives the following charge to the U.S. Department of Housing and Urban Development (HUD):

> *The Secretary, in cooperation with other Federal agencies, shall conduct research on strategies to reduce the risk of lead exposure from other sources, including exterior soil and interior lead dust in carpets, furniture, and forced air ducts.*

The research mandated by Section 1051 also impacts the research being conducted by the U.S. Environmental Protection Agency (EPA) in response to Title X. EPA's research focuses on defining lead-based paint hazards under Section 403 of the amended Toxic Substances Control Act (Title IV: Lead Exposure Reduction). As a result, EPA is assisting HUD in their effort to conduct research under Section 1051.

Residential carpets are included as an indirect lead source in Section 1051 as they become reservoirs for dust from interior sources, for exterior soil tracked into the house, and for dust and soil introduced to the house from outside sources such as work environments. Foot traffic lodges dust and soil deep into the carpet, making it difficult for typical cleaning efforts to remove all dust and soil. In houses containing lead-based paint or surrounded by lead-contaminated soil, the dust and soil within carpets can be highly contaminated with lead. Young children are especially prone to exposure to carpet dust and soil, as their activities bring them into frequent contact with available carpeted surfaces, and their mouthing tendencies result in dust and soil ingestion.

Residential furniture, upholstery, and window treatments (e.g., draperies), as well as forced air ducts, are indirect lead sources when they become reservoirs for interior dust generated by renovation, abatement, or peeling paint residue, exterior dust which enters the housing unit through doors and windows, and exterior soil tracked into the home on shoes and clothes. Children can come into direct contact with lead-dust on furniture, upholstery, and window treatments, while lead-dust in air ducts can be circulated throughout the house or can be directly encountered as a result of renovation activities.

This report presents the results of studies which have measured the extent of potential lead exposure associated with carpets, furniture[1], and forced air ducts, and/or which have investigated methods of mitigating such lead exposures. Determining the extent to which these sources pose a health hazard to children as a result of exposure to lead, and any necessary action to be taken as a result, requires an investigation into three research issues. First, an appropriate procedure for measuring the amount of lead in dust and soil within these surfaces must be identified. Second, the relationship between the measured lead dust in these surfaces and blood-lead concentrations in children exposed to such surfaces must be characterized. Third, procedures must be developed to mitigate any lead hazard in these surfaces, either through appropriate cleaning procedures or removal. This report focuses on available information on each of these three issues.

The findings in this literature review report will assist EPA in determining areas in which further research is warranted to address issues within Title X. For example, it may be necessary to develop standards for lead levels within dust and soil from the sources identified in Section 1051, where the standards have a basis in human health effects.

1.1 REPORT ORGANIZATION

The findings presented in this report, summarized in Chapter 2, have been previously documented in published governmental and private-sector literature, as well as in significant unpublished reports, such as government documents. The approach taken to performing the literature reviews is presented in Chapter 3. General information encountered on lead contamination of residential carpets, furniture, and air ducts is presented in Chapter 4. Chapter 5 contains detailed summaries of the published literature, and a complete reference list is provided in Chapter 6. Chapters 2, 4, and 5 contain subsections for each of the three lead sources.

1.2 PEER REVIEW COMMENTS

This study was reviewed independently by members of a peer review panel. Comments which are important for interpreting the study results or which had an important impact on the report are discussed below.

One peer reviewer requested that the report emphasize the limited number of articles that specifically address lead measurement, its association with blood-lead concentration, and mitigation in regard to dust and soil from carpets, furniture, and air ducts. Furthermore, most articles often contained only a limited amount of information in these areas. These points were more highly emphasized in the executive summary and Chapter 2.

Another peer reviewer addressed the report's use of the term "lead exposure" when a more specific term should be used, such as when referring to a certain type of lead measurement (e.g.,

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[1] Further references to the term “furniture” in this document are to furniture, upholstery, and window treatments (e.g., draperies).

lead loading, lead concentration). As a result, all occurrences of the term "exposure" were reviewed for proper usage. The term "exposure" is now used to refer to general human contact with lead in environmental media. Similarly, references to "health effect" were replaced with phrases like "association with blood-lead concentration," as data in the encountered studies only considered the association between lead levels in various media and blood-lead concentration, but did not consider specific health effects associated with lead exposure.

A third peer reviewer provided additional, recent references for consideration, most of which were included in the report due to their relevant information on carpets. Some of these references characterize carpet-dust and how its presence contributes to overall exposure to pollutants such as lead. The reviewer wished to emphasize that an integrated approach to reducing exposures to a series of pollutants would be more efficient than a strategy that focused on a single pollutant. Some relevant information on an integrated strategy was added to this report, such as the role of carpets and upholstery in promoting "sick building syndrome," or the tendency of some buildings to promote unhealthy symptoms in its residents. However, it was necessary to keep the report focused on its primary objective of addressing lead exposure associated with carpets, furniture, and forced air ducts. The reviewer also emphasized that the report's initial claim that carpets may act as a mitigator of lead exposure by its ability to trap certain types of dust within its fibers, thereby reducing its bioavailability to children, is primarily relevant only to clean carpets. Furthermore, if dust is not removed completely from a carpet, the carpet must frequently be tested for surface lead levels as the deeply-embedded dust can be returned to the surface via continued cleaning and disturbance. The report has modified text in Chapters 2 and 4 to emphasize these issues raised by the reviewer.

2.0 FINDINGS AND CONCLUSIONS

Carpets, furniture, and air ducts are considered both a source and a sink for pollutants in the home, including lead, with a greater potential for exposure associated with increased age of the source (Roberts et al., 1996). However, few documents were identified that contained relevant information to characterize lead exposures associated with these three sources. Typically, the available information was limited, and the encountered studies did not necessarily address the specific objectives of this report. Therefore, to adequately characterize lead exposures associated with carpets, furniture, and air ducts, and to determine appropriate mitigation methods for these exposures, it is necessary to conduct a considerable amount of additional research.

Sections 2.1 through 2.3 present relevant findings and conclusions of the documents encountered in the literature search, according to the lead source. See Chapters 4 and 5 for details, including the references where these key findings and conclusions were cited.

2.1 CARPETS

For most children, floor dust lead is considered a prominent source of lead exposure. Carpets can hold large amounts of dust and soil (one study indicating 15 to 140 times more, while another reference cites up to 400 times more per square meter, compared to uncarpeted floors), thereby increasing the likelihood of carpets being lead-contaminated relative to other surface types. This is partially due to less particle movement for carpeted surfaces relative to hard surfaces as a result of dust being trapped within carpet fibers. Thus, carpets can have high dust-lead loadings (i.e., amount of lead per unit area of carpet) relative to other surfaces, but due to equally high dust loadings, they may have only moderate dust-lead concentrations (i.e., amount of lead per unit mass of dust). For example, one study (the CLEAR study) reported that geometric mean lead loadings for carpet dust can be approximately 18 times higher than that for uncarpeted floors and 6 times higher than that for window sills, while reporting lower lead concentrations in carpet-dust relative to these other surfaces.

Even if a carpet contains a high amount of lead-contaminated dust and soil, the dust collection method employed in a particular study also determines the magnitude of the reported dust-lead loadings. For example, DVM and wipe collection methods tend to collect only surface dust on carpets, and not the more deeply-embedded dust. Users of these methods indicate that only carpet dust which is directly bioavailable to children (i.e., surface dust) should be of interest to characterize for lead. In fact, certain carpet data associated with these dust collection methods have suggested that clean carpets may act as a short-term mitigator of floor dust, as it can trap and hold a certain portion of the available floor dust, reducing its bioavailability to children. However, additional data are necessary to verify this hypothesis.

Other dust collection methods attempt to collect all dust within a sampling area. However, while they may report higher dust-lead loadings on carpets compared to methods that sample only surface dust, even their reported loadings may be underestimated due to lower dust collection efficiencies on carpets relative to other surfaces (e.g., Blue Nozzle vacuum). This is especially apparent with fine dust, which tends to get trapped among the carpet fibers and is more difficult to collect as a result. The following factors are among those most significantly associated with vacuum dust collection efficiency on carpets: carpet type, relative humidity, vacuum particle lifting velocity, dust particle size, magnitude of static pressure in the vacuum nozzle, and presence of agitator bars on the vacuum. Dust collection efficiencies can also decline with increasing dust loadings. As dust collection efficiency is a function of the method being used, and as different methods may target different subsets of dust, a proper carpet dust-lead characterization specifies the dust collection method and protocol that was used.

The following variables were found to be statistically significant predictors of dust-lead loadings in carpets: soil-lead concentrations, exterior dust-lead loadings, the practice of removing shoes prior to entry, use of walk-off mats at entrances, and use of vacuums with agitators. The first four predictors imply that a major source of lead dust in carpets is track-in from exterior sources.

The extent that lead within carpet dust is made available to children tends to be heightened when any of the following is present: having shag rugs, using either a canister vacuum (with no agitator) or no vacuum cleaner, using a vacuum cleaner with loose belts or a full dust collection bag; vacuuming less than once per week, location of unit near heavy traffic, and exposure to remodeling activities, deteriorated paint, or paint removal activities. When attempts are made to clean the carpet through normal vacuuming, one may remove less than 10% of total lead in the carpet, especially in high-traffic areas where dust (and lead) is deeply embedded. While most of the dust that is removed is from the surface, the vacuuming may also bring some of the deeply-embedded dust to the surface. However, the extent to which lead remaining deeply embedded in the carpet is bioavailable to children may be limited.

Carpet dust-lead concentration was found to be significantly associated with such factors as presence of lead-based paint, entryway dust-lead concentration, soil-lead concentration, traffic density, and house age. As lead collects within a carpet, lead concentrations in the carpet-dust can exceed that in exterior dust and soil, despite normal cleaning efforts (Roberts et al., 1996). However, some studies disagree on the relationship between carpet dust-lead concentration and dust particle size. Several studies report that lead concentrations appear higher in fine dust than in coarse dust, which can partially explain higher concentrations in high-traffic areas and in older carpeting. However, more recent studies (e.g., Wang et al., 1996) have noted that interior carpet dust-lead concentration often increases as dust particle size increases. The different conclusions are likely the result of lead-based paint replacing leaded gasoline emission residue as the primary source of contamination. Most studies observe high positive correlation between lead concentrations and lead loadings in carpet dust.

Most studies that investigate links between lead in carpet dust and blood-lead concentrations in children observe a significant positive correlation between the two measures. In general, dust-lead loading has a higher correlation with blood-lead concentration than dust-lead concentration. However, the direct effect of lead in carpet dust on blood-lead concentration is reduced when taking into account other factors such as mouthing behavior, socioeconomic status, and lead levels in other media.

Successful lead level reduction within carpet was achieved through carpet cleaning by using cleaning solutions that contain phosphate or polyphosphate groups, which bind to dust particles and reduce the electrostatic interaction between the carpet and lead-dust. Then, detergents within the solution can remove the dust and the accompanying lead. An accompanying reduction in blood-lead concentration may occur if repeated cleaning is done.

One study (Ewers et al., 1994) concluded that vacuum cleaning efforts of "chronically contaminated" carpets may actually increase surface dust-lead loadings to children if not sufficiently repeated over time. This is due to bringing more deeply-embedded dust to the surface with each cleaning iteration. While surface dust-lead loadings within old, contaminated carpets decreased, on average, after ten iterations of cleaning the carpets with a HEPA vacuum, no significant change in dust-lead concentrations was observed across the cleaning iterations. Thus, in cases where deeply-embedded dust cannot be removed in its entirety as a result of cleaning, or when the carpet is highly contaminated due to lead-based paint, remodeling efforts, or proximity to major lead sources such as a smelter, it may be more practical to replace, rather than clean, a chronically-contaminated carpet.

2.2 FURNITURE

This literature search identified only a limited amount of information on lead exposures associated with dust within residential furniture, upholstery, and window treatments. While some useful information was encountered concerning the extent to which such surfaces may be lead-contaminated, many open questions exist that only further research can answer.

In units with a potential for lead contamination, average dust-lead loadings on furniture, upholstery, and window treatments are generally lower than for other surfaces, such as floors, window components, walls, and air ducts. Most of the averages reported in these studies (using various dust collection methods) are less than 100 µg/ft^2, with higher results associated with units with a higher potential for dust contamination. The extent to which these surfaces act as a sink for lead and dust is uncertain and may be dependent on the type of fabric.

Among the reviewed studies, the following methods were used or developed for sampling dust and/or measuring lead in dust from furniture, upholstery, and window treatments: the High Volume Furniture Sampler (HVFS), BRM, DVM, wipes (hard surfaces only), and nitric acid leaching (net curtains). The HVFS is a modified version of the HVS3 and has been developed to sample dust from lightweight fabric found on upholstered surfaces; however, no field study using the HVFS was encountered.

One study evaluated a cleaning protocol that involved both dry and wet cleaning iterations on a series of surfaces, including upholstery. When the average percentage of the total amount of lead in a housing unit collected by this method was determined for each surface, the percentage associated with upholstered surfaces was low.

In the Baltimore R&M study, the correlation between upholstery dust-lead loadings and blood-lead concentrations was significantly positive. However, as upholstery dust-lead is often correlated with other lead exposure variables, such as floor dust-lead and soil-lead, this positive correlation coefficient should not be interpreted as the degree to which upholstery dust causes a change in blood-lead concentration. In order to characterize the pathway of lead from upholstery to children's blood (and perhaps hands), additional data collection and analyses are needed.

Foreign-made, vinyl mini-blinds that contain added lead may present a lead hazard as documented by the CPSC when exposed to direct sunlight for prolonged periods and when children come into contact with the resulting lead-contaminated dust. Therefore, such mini-blinds would be a direct source of lead, rather than a way by which lead from an indirect source, such as lead-based paint, would be made available to children.

Few, if any, studies were encountered which investigated procedures for mitigating lead exposures in furniture, upholstery, or window treatments. Available data were limited and inconclusive. While one study provided evidence that some vacuum cleaning procedures may not reduce lead levels substantially on furniture, this was not investigated on heavily-contaminated surfaces. Some evidence exists that a greater percentage of lead can be removed from furniture versus carpets when using a procedure of both dry vacuum and wet cleaning. In addition, there is evidence that hand-held vacuums with a power head can remove more dust, including deep dust, from furniture, upholstery, and carpeted steps, compared to other vacuums. However, additional research is necessary to justify these claims.

2.3 AIR DUCTS

While only limited information was encountered in this literature search on lead exposures associated with dust within air ducts, a consensus across studies was that air ducts can contain high amounts of dust and lead. This was due partially to the general lack of cleaning of air ducts over time and the ability of lead particles to enter air ducts from outside of the unit via ventilation filters. Most of the encountered articles provided only preliminary information on lead exposures associated with air ducts; additional research will be necessary to address the many open questions and to provide a more scientific characterization.

In units with a potential for containing lead hazards, dust-lead loadings in air ducts typically exceeded 100 µg/ft^2, with individual samples often exceeding 1,000 µg/ft^2. Lead levels can vary considerably among dust samples within the same unit and in different units. Older ductwork and HVAC systems, as well as vacant units in which no cleaning is performed and HVAC systems may not be used, tend to have high dust loadings, and therefore, higher dust-lead loadings when a lead source is present. Several methods were used across studies to collect dust in air ducts. As air ducts often have metal surfaces, issues concerning static electricity must be considered when sampling dust from air ducts.

In a typical housing unit in the Comprehensive Abatement Performance (CAP) study, average dust-lead loadings from air ducts exceeded all other sampled surfaces except for window wells and entryways. The high dust-lead loadings associated with window wells and entryways are likely the result of a high rate of exposure to outdoor lead sources. This exposure may also explain, to a lesser degree, high dust-lead loadings in air ducts, as one study (Cram et al., 1994) hypothesizes that small particle sizes found in outdoor dust can penetrate ventilation filters and deposit into air ducts. Therefore, this finding in the CAP study supports the hypothesis that interior surfaces increase their potential for containing lead-contaminated dust as their exposure to exterior sources increases.

It is unclear to what extent dust lead in air ducts is accessible to children. Children would not typically be expected to encounter the dust lodged in air ducts directly. One case study found that dust-lead levels in living areas outside of contaminated air ducts can be orders of magnitude lower than what is found in the air ducts. However, if dust in air ducts is disturbed, it is more likely to be introduced to the air and to nearby surfaces with which children can come into direct contact. In particular, HVAC ductwork removal can yield extensive contamination of surfaces in the general area of the ductwork.

Using the cleaning methods in the Toronto pilot demonstration study, lead in dust within air ducts has been found to represent a large percentage of the total lead in recoverable dust within a housing unit. In this study, an average of 30% of the total lead removed by a specific household cleaning procedure was removed from ductwork. Only floors had a higher average percentage (42%). In nearly half of the housing units in this study, the percentage for air ducts exceeded 50%.

Only one study (the Baltimore R&M Study) estimated (in a quantitative manner) the association between blood-lead concentrations in children and dust-lead levels found in air ducts. This relationship was expressed as a simple correlation coefficient. Unlike correlations between blood-lead concentrations and dust-lead levels on other surfaces, the correlation coefficient involving dust-lead levels from air ducts was not significant at the 0.05 level. However, this analysis was based on a small sample size and did not adjust for the effects of other exposure variables such as lead in floor dust and soil. Moreover, as evidence of a significant correlation was observed between air duct dust-lead levels and lead levels on other surfaces, such as floors, even significant correlation coefficients should not be interpreted as the degree to which air duct dust causes a change in blood-lead concentration. In order to characterize the pathway of lead from air ducts to children's blood, additional data collection and analyses are needed.

To investigate the environmental source of lead exposure in children, one study (the Omaha study) considered the relationship between the isotopic ratio of ^{206}Pb to ^{207}Pb on hand dust and on dust from other surfaces. A significantly positive linear relationship was observed between the annual mean isotopic ratio for hand wipes and the annual mean isotopic ratio for air ducts. However, as adjustments for the effects of other environmental sources were not made in this analysis, it is uncertain as to the extent that this relationship is the result of high correlation with other exposures.

Only one study (the Toronto study) evaluated an approach for cleaning lead-contaminated dust from air ducts, as part of an overall house cleaning protocol. A procedure using a portable-unit-powered suction head or nozzle was applied to the air duct surfaces. The protocol specified that no additional cleaning was to proceed until 24 hours after completing the ductwork cleaning, and that the air distribution fan was to be run following cleaning with duct outlets covered. The evaluation noted that air duct cleaning failed to produce more airborne dust relative to other segments of the cleaning operation. As a result, the evaluation indicated that it may not be necessary to conduct air duct cleaning prior to any other cleaning in the unit when attempting to minimize lead levels in the air. However, when considering air-lead levels that result from cleaning other surfaces following air duct cleaning, the percentage of lead in air that remains from air duct cleaning is uncertain.

3.0 APPROACH TO CONDUCTING THE LITERATURE REVIEW

This chapter provides information on how the search and procurement of relevant articles on lead exposure and mitigation in carpets, furniture, and air ducts was conducted. While articles were obtained through 1997, the electronic literature search was conducted from February to July, 1996. It focused on evaluating lead exposures associated with dust and soil existing within residential carpets, the extent to which these lead exposures are associated with blood-lead concentrations in young children, and procedures for mitigating these exposures. The electronic literature search identified titles and abstracts within a number of on-line index databases. Those index databases included in the search procedure are presented in Table 3-1 and were selected based on past experience of lead-related searches and on a preliminary search for articles pertaining to carpet-lead.

Table 3-1. Scientific Index Databases Considered in the Literature Search

Database	Description	Year(s) Searched
NTIS	Provides access to government-sponsored research; analyses prepared by federal agencies, contractors, and grantees; and unclassified, publicly-available reports (The National Technical Information Service, U.S. Department of Commerce)	1964-1996
MEDLINE®	Covers biomedicine-related articles from journals published throughout the world (Knight-Ridder Info.)	1966-1996
Toxline®	Covers articles pertaining to the adverse effects of chemicals, drugs, and physical agents on living systems (Knight-Ridder Info.)	1965-1995
Occ. Saf. & Hth.	Covers all aspects of occupational safety and health found in over 2,000 journals and 70,000 monographs and technical papers (Knight-Ridder Info.)	1973-1995
EMBASE	Covers biomedicine-related articles found in over 3,500 biomedical and pharmacological journals published throughout the world (Elsevier Science B.V.)	1974-1996
BIOSIS PREVIEWS®	Covers research in the biological and biomedical sciences, including primary journal and monograph titles, and citations from meeting abstracts, reviews, books, notes, letters, selected institutional and government reports, and research communications (BIOSIS)	1969-1996
SciSearch®	Covers published literature pertaining to science and industry (Inst. for Sci. Info.)	1974-1996
IAC**K**	Covers published health and wellness information in a wide variety of publications, even non-scientific magazines (Inform Access Co.)	1976-1996
CA SEARCH®	Covers literature pertaining to chemistry and its applications (American Chemical Society)	1967-1996

The search strategy focused on the areas of interest in this report: measurement, association with blood-lead concentration, and mitigation. The on-line literature searches for information on all three exposure sources cited in Section 1051 (carpets, furniture, air ducts) were performed together, to facilitate the overall effort and to reduce duplication.

The search strategy for each of the three exposure sources is presented in Table 3-2. For each source, the search strategy consisted of three search criteria (i.e., rows in Table 3-2). Each criterion consisted of a series of keywords connected by Boolean operators ("and", "or"). For each criterion, titles and abstracts (if available) for articles satisfying the criterion (through search of titles, descriptors, and identifier fields within the on-line database records) were provided for review.

As seen in Table 3-2, the first criterion in the carpet search strategy attempted to identify articles that jointly addressed carpet and lead, where lead was identified through the word "lead", through CAS registry numbers, or by the abbreviation "Pb." The second criterion focused on lead-dust collection, lead-dust mitigation, and lead-dust with mention of children, while not restricting component or substrate types (e.g., carpets). Therefore, information from this second criterion could be relevant for all three Section 1051 sources. Finally, the third criterion considered articles on dust collection from carpets, focusing on sampling efficiency and comparability issues, without limiting the search to only articles that explicitly address lead (as the previous two criteria did).

Other procedures were also used to identify relevant articles. For example, reference citations within reviewed articles provided additional articles. EPA and HUD identified relevant governmental studies and previous literature review efforts. Articles cited in these previous review efforts were obtained for further review for this report. Articles were also identified through efforts on other EPA tasks in the lead exposure area and from the external peer reviewers to this report. These articles were identified and reviewed throughout the preparation of this report. Results from selected unpublished data analyses performed for EPA using data from published studies were also included when the results were relevant for this report. Unpublished findings are cited as such in this report. Relevant studies and articles continued to be identified throughout the preparation of this report.

After reviewing titles, abstracts, and text for reports and articles identified through the literature search, the following numbers of documents were identified as containing the most relevant information concerning lead-dust measurement, association with blood-lead concentration, and mitigation:

- 59 documents relative to residential carpet.
- 11 documents relative to residential furniture, upholstery, and window treatments
- 8 documents (from 7 studies) relative to residential air ducts.

Table 3-2. Criteria Used in the Literature Search for Articles on Lead Measurement, Hazard Identification, and Mitigation Techniques

Search Criteria (= First Condition AND Second Condition AND Third Condition)

<table>
<tr><th>Criterion #</th><th>First Condition</th><th>Second Condition</th><th>Third Condition</th></tr>
<tr><td colspan="4">Lead Exposures in Carpets</td></tr>
<tr><td>#1</td><td rowspan="2">Lead[1] OR Pb OR a particular registry number in Chemical Abstracts ((7439-92-1 (Pb) OR 15752-86-0 (Pb-202) OR 139-66-26-2 (Pb-204) OR 13966-27-3 (Pb-206) OR 14119-29-0 (Pb-207) OR 13966-28-4 (Pb-208) OR 14255-04-4 (Pb-210))</td><td>Carpet* OR Rug?</td><td>---</td></tr>
<tr><td>#2</td><td>Dust?</td><td>Vacuum* OR Wipe? OR Wiping OR Sample? OR Sampling OR Clean* OR Abate* OR Abating OR Mitigat* OR Remove? OR Removing OR Removal OR Child? OR Children OR Kid? OR Infant? OR Toddler?</td></tr>
<tr><td>#3</td><td>Carpet* OR Rug?</td><td>Dust?</td><td>Efficien* OR Compare? OR Comparison? OR Comparing OR Effective*</td></tr>
<tr><td colspan="4">Lead Exposures in Furniture, Upholstery, and Window Treatments</td></tr>
<tr><td>#1</td><td rowspan="2">Lead[1] OR Pb OR a particular registry number in Chemical Abstracts ((7439-92-1 (Pb) OR 15752-86-0 (Pb-202) OR 139-66-26-2 (Pb-204) OR 13966-27-3 (Pb-206) OR 14119-29-0 (Pb-207) OR 13966-28-4 (Pb-208) OR 14255-04-4 (Pb-210))</td><td>Drape? OR Curtain? OR Blinds OR Furniture OR Upholster? OR Textile? OR Miniblind? OR (Mini()Blind?)</td><td>---</td></tr>
<tr><td>#2</td><td>Dust?</td><td rowspan="2">Vacuum* OR Wipe? OR Wiping OR Sample? OR Sampling OR Clean* OR Abate* OR Abating OR Mitigat* OR Remove? OR Removing OR Removal OR Child? OR Children OR Kid? OR Infant? OR Toddler? OR Blood</td></tr>
<tr><td>#3</td><td>Drape? OR Curtain? OR Blinds OR Furniture OR Upholster? OR Textile? OR Miniblind? OR (Mini()Blind?)</td><td>Dust?</td></tr>
<tr><td colspan="4">Lead Exposure in Forced Air Ducts</td></tr>
<tr><td>#1</td><td rowspan="2">Lead[1] OR Pb OR a particular registry number in Chemical Abstracts ((7439-92-1 (Pb) OR 15752-86-0 (Pb-202) OR 139-66-26-2 (Pb-204) OR 13966-27-3 (Pb-206) OR 14119-29-0 (Pb-207) OR 13966-28-4 (Pb-208) OR 14255-04-4 (Pb-210))</td><td>Airduct* OR (Air()Duct*) OR Register? OR Ventilation OR HVAC</td><td>House? or Home? or Resident* or Dwelling?</td></tr>
<tr><td>#2</td><td>Dust?</td><td>Vacuum* OR Wipe? OR Wiping OR Sample? OR Sampling OR Clean* OR Abate* OR Abating OR Mitigat* OR Remove? OR Removing OR Removal OR Child? OR Children OR Kid? OR Infant? OR Toddler? OR Blood</td></tr>
<tr><td>#3</td><td>Airduct* OR (Air()Duct*) OR Register? OR Ventilation OR HVAC</td><td>Dust? OR Clean* OR Abate* OR Abating OR Mitigat* OR Remove?</td><td>(Child? OR Children OR Kid? OR Infant? OR Toddler?) AND Blood</td></tr>
</table>

* Any extension to this word was allowed (e.g., carpet, carpets, carpeting).
? Only single-character extensions to this word were allowed (e.g., rugs, samples, sampled).
[1] Lead as a noun, pronounced "led", appearing in the title, descriptor, or identifier fields of the on-line database records.

Some of these documents addressed issues concerning dust in carpets, furniture, and air ducts, but not specifically investigated lead levels in the dust. Such dust issues were considered relevant to this report when presented in the context of how dust promotes exposure to pollutants in general, of which lead would be included. The titles and authors of these documents are provided in the reference list within Chapter 6, according to lead source. While other documents not included in the reference list may also provide some relevant information, the information in these documents provides the basis for the presentation in this report.

3.1 KEY FIELD STUDIES

While the literature search identified published articles and reports for a variety of field and laboratory studies, there were a few studies that were key in providing useful information on multiple research areas within a lead source, or on multiple lead sources. These studies are the Baltimore R&M study, the Rochester Lead-in-Dust study, the Toronto pilot demonstration project for cleaning protocols, and the CLEAR study. This section provides background information on these key studies; additional details, including references on these studies, are provided in the specific areas of Chapters 4 and 5 where results of these studies are discussed.

Lead-Based Paint Abatement and Repair & Maintenance (R&M) study

Between January 1993 and November 1994, EPA performed the pre-intervention (baseline) phase of the Lead-Based Paint Abatement and Repair & Maintenance (R&M) study. This longitudinal study, performed in Baltimore, Maryland, investigated the short-term and long-term efficacy of a variety of R&M intervention strategies to reduce residential exposure of children to lead in paint and in settled dust. One-hundred and seven housing units containing a total of 140 children were included in the study. Of these units, 75 were low-income units (some vacant, some occupied) built prior to 1941 and scheduled to receive R&M interventions in this study at up to three levels (low, mid, high), 16 were low-income dwellings built prior to 1941 and having lead-based paint abatement performed between 1988 and 1992, and 16 were modern urban dwellings built after 1979 and considered free of lead-based paint (serving as control units). Environmental data cited in this literature review report were collected following enrollment of the unit in the study, prior to conducting any R&M intervention, and thus represent baseline conditions for the units. For occupied units, children's blood-lead concentration data were collected (using venipuncture) at enrollment, while for vacant units, these data were collected following R&M intervention, when families moved into the units.

Among the surfaces sampled for dust were floors (composite samples from carpeted and/or uncarpeted surfaces), upholstered surfaces, and air ducts, thereby addressing the three surfaces of interest to this report. However, as the amount of carpeted surface represented in the floor-dust composite samples was generally low for all but the modern urban control units, this study was not used to provide information on lead hazards associated with carpet dust. Window sills and window wells were also sampled for dust. All dust samples were collected using the BRM cyclone sampler (Section 5.1.1.1).

Rochester Lead-in-Dust Study

Performed in 1993, the Rochester Lead-in-Dust study was a cross-sectional epidemiological study of 205 children aged 12-31 months who lived in the city of Rochester, NY, and had no known history of elevated blood-lead concentrations. These children tended to reside in older housing (84% of the units were built prior to 1940) and to belong to lower-income families. The objective of this study was to evaluate the effect of dust-lead contamination on the blood-lead concentrations of these children. The study also considered various dust sampling methods (the BRM vacuum sampler, the DVM vacuum sampler, and the wipe method) to investigate which result in dust samples whose lead levels are most highly correlated with children's blood-lead concentration.

Within each housing unit, up to 36 interior dust samples were collected from surfaces most accessible to the child or known to contain dust with high lead levels (carpeted floors, uncarpeted floors, window sills, and window wells). The surface type was recorded (e.g., low carpet, high carpet, or uncarpeted). Venous blood samples were collected from each participating child and analyzed for lead. Therefore, this study provides useful information on dust-lead levels on carpeted surfaces, how these levels are related to blood-lead concentration, and how methods used to collect dust samples from carpets (among the other surfaces) rate in terms of how lead levels in dust correlate with blood-lead concentration.

The Rochester study also had a laboratory evaluation phase where the recovery rates of lead in dust were evaluated for the three dust collection methods. This experiment was done on carpet, linoleum, and wood. Therefore, this phase of the study provides additional information on the efficiencies of different carpet dust collection methods.

Toronto Pilot Demonstration Project

In the spring of 1988, the City of Toronto, Department of Public Health, conducted a pilot demonstration project in eight housing units within the South Riverdale community of Toronto. The objective of this study was to evaluate the effectiveness of two cleaning procedures aimed to reduce lead in interior dust. Interior dust was assumed to be lead-contaminated as a result of contaminated exterior soil, as the community was in an industrial, high-traffic area in the vicinity of a secondary lead smelter. This demonstration study preceded a wide-reaching soil abatement (removal and replacement) and housedust cleaning program performed within the South Riverdale Lead Reduction Program in over 1,000 housing units in two Toronto neighborhoods.

The cleaning procedure directed that dry HEPA vacuums be used to clean dust from floors, air ducts, and other surfaces (walls, shelving, upholstery, draperies, etc.). In addition, wet cleaning using tri-sodium phosphate-based cleaners, was performed on floors, carpets, upholstery, and walls. In this process, the study measured total lead removed from each surface type. Therefore, the study provided information on the efficacy of the different cleaning procedures and the contribution of dust on various surfaces to total lead amounts in household dust.

The Children's Lead Exposure and Reduction (CLEAR) Study

Conducted in Jersey City, NJ, the CLEAR study investigated how household cleaning contributed to reducing blood-lead concentration in children. Households recruited for this study had a child aged two years or less. Either this child had a blood-lead concentration in the range of 8-20 µg/dL, the household had lead-contaminated house dust or paint, or the child had an older sibling with a blood-lead concentration exceeding 10 µg/dL.

In initial visits to 216 housing units from 1992-1994, dust samples were collected from the younger child's primary activity area in the house. Included in these samples were 376 samples collected from carpets using a vacuum method developed specifically for this study (Section 5.1.1.4). Thus, this study provided useful information on baseline lead levels in residential carpets. In addition, results of laboratory studies to characterize the efficiency of the CLEAR Study vacuum on carpets were available and are cited in this report.

4.0 GENERAL INFORMATION ON LEAD CONTAMINATION IN CARPETS, FURNITURE, AND AIR DUCTS

This chapter provides an overview of information published on lead contamination of dust and soil within residential carpets, furniture, and forced air ducts. This information is presented to provide the reader with a general summary of published information on lead exposures associated with these sources. More detailed presentation is provided in Chapter 5, within the targeted research areas of measurement, association with blood-lead concentration, and mitigation. Reference citations are referred to Chapter 6.

It is difficult to reach a consensus across studies on the extent of lead contamination of dust within carpets, furniture, and air ducts, and how such lead exposures may affect children's blood-lead concentration. This is due, in part, to study-to-study differences in the methods used to collect dust from these surfaces and in the underlying conditions in which the studies took place. Different dust sampling methods have different collection efficiencies and other unique properties which affect the amount and type of dust collected from various surfaces (see Chapter 5). As a result, comparing results across studies must be performed with caution, and any conclusions made from these studies must be accompanied by statements indicating the method of dust collection and analysis and any circumstances unique to each study.

4.1 CARPETS

Many researchers have acknowledged the role of carpets as a vast reservoir for household dust and exterior soil introduced to the housing unit, providing a large potential for dust-lead exposure to children. For example, Dybendal et al., 1991, indicates that carpeted floors can accumulate from 4 to 5 times more dust, proteins, and allergens per unit area than smooth floors. Roberts et al., 1995b, report that old carpets can have up to 400 times more dust per square meter compared to uncarpeted floors. To investigate dust collection from carpets, a study in three housing units found that dust collected from carpeted floors was from 15 to 140 times greater in quantity than dust from uncarpeted floors (Roberts et al., 1988). This finding occurs despite findings in other studies that the efficiencies of dust collection methods are generally low for carpets relative to other types of surfaces (USEPA, 1995a,b). Carpet dust contains more silicaceous material, while greater amounts of dry, organic matter is present in airborne dust and dust on uncarpeted surfaces (Roberts et al., 1988).

The role of carpets in promoting indoor surface pollution has been recognized in articles on "sick building syndrome" (e.g., Raw et al., 1993). Occurrences of "sick building syndrome" (i.e., the effect that certain buildings have on human health symptoms), as well as high levels of airborne dust, have been associated with amount of carpet and other fabric-covered surfaces relative to the amount of living area (i.e., the "fleece factor"). The level of association is heightened in houses with small volume, low air exchange rates, and high levels of dirtiness (Ozkaynak et al., 1996). "Sick building syndrome" can occasionally be a precursor to exposure to harmful pollutants, including lead.

Analysis of baseline dust samples from carpeted surfaces within 216 housing units participating in the CLEAR Study (Section 3.1) corroborate evidence that carpets can hold large amounts of dust and soil, thereby increasing the likelihood of carpets being lead-contaminated relative to other surface types (Adgate et al., 1995). In these units, both the geometric mean dust loading and the geometric mean lead loading were approximately 18 times higher in carpets than in uncarpeted floors and six to eight times higher than that for window sills. As the CLEAR Study vacuum was used to sample dust from carpets while wipe techniques were used to sample dust from the other surfaces, caution must be taken when comparing results between carpets and other surfaces.

Very high lead levels in carpet-dust have been measured and documented in other studies as well. For example, a study conducted in 38 Seattle units built prior to 1950 contained an average carpet-lead loading of 12,000 $\mu g/m^2$ (1,115 $\mu g/ft^2$) and an average carpet lead concentration of 1,130 µg/g within fine dust (< 150 microns) (Roberts et al., 1991a).

The presence of carpets does not always imply that dust samples taken from carpets will have higher dust-lead loadings for a given sampling method relative to other surfaces. For example, consider dust-lead loading data from the National Survey of Lead-Based Paint in Housing (USEPA, 1995c) and the Rochester Lead-in-Dust study (Section 3.1). For each study, Table 4-1 presents a surface-by-surface breakdown of the number and percentage of housing units whose area-weighted geometric mean dust-lead loadings exceeded certain threshold values. These statistics were calculated from public use databases to support EPA's Section 403 rulemaking efforts and were not previously published. Only dust samples collected by wipe methods are represented for the Rochester study, while the dust-lead loadings in the HUD National Survey were converted from Blue Nozzle vacuum loadings to equivalent wipe loadings based on conversion methods developed for the Section 403 rulemaking activity.

Note from Table 4-1 that in both studies, carpeted surfaces tended to have a slightly lower incidence of high dust-lead loadings compared to uncarpeted surfaces, and a considerably lower incidence compared to window sills and window wells. One can hypothesize the following from this finding:

- As other studies have shown that wipe methods typically have lower dust collection efficiency on carpets than on other surfaces, this finding may be the result of the dust collection method assumed.

- If dust samples collected from wipe methods represent that dust which can easily come into contact with children, then these results suggest that carpets may act as a short-term mitigator of lead exposure associated with floor dust. Carpets can retain contaminated dust within its fibers, thereby reducing the bioavailability of the lead. However, if this dust is able to reach the surface over time, such as by repeated vacuuming or disturbance, it may eventually pose a lead hazard to children.

Table 4-1. Percentage of Surveyed Housing Units in Two Studies With Area-Weighted Geometric Mean Dust-Lead Loadings Exceeding Various Thresholds, for Four Types of Surfaces, Including Carpeted Floors (Wipe Collection Techniques Assumed)

Surface Type Sampled for Dust	# Surveyed Units		Dust-Lead Loading Threshold	% of Surveyed Units with Geometric Mean Dust-Lead Loadings Exceeding the Threshold	
	HUD National Survey	Rochester Study		HUD National Survey[1]	Rochester Study[2]
Carpeted Floors	241	176	25 µg/ft^2	36.9%	14.8%
			50 µg/ft^2	18.3%	4.5%
			100 µg/ft^2	5.8%	1.7%
			200 µg/ft^2	2.1%	1.1%
Uncarpeted Floors	213	197	25 µg/ft^2	31.9%	29.4%
			50 µg/ft^2	20.2%	9.6%
			100 µg/ft^2	10.3%	4.6%
			200 µg/ft^2	4.7%	2.5%
Window Sills	245	195	25 µg/ft^2	53.1%	95.4%
			50 µg/ft^2	43.3%	90.3%
			100 µg/ft^2	33.1%	68.7%
			200 µg/ft^2	24.9%	47.7%
Window Wells	112	189	25 µg/ft^2	88.4%	100%
			50 µg/ft^2	81.3%	97.9%
			100 µg/ft^2	72.3%	94.7%
			200 µg/ft^2	54.5%	89.4%

1 The Blue Nozzle vacuum lead loadings for dust samples collected in the National Survey were converted to wipe lead loadings prior to calculating the statistics in this column. The conversion equation is (Wipe lead loading)=a*(Blue Nozzle lead loading)^b, where a=11.4 and b=0.690 for floors, a=5.79 and b=1.08 for window sills, and a=7.37 and b=0.752 for window troughs.

2 Only data for samples collected using wipe techniques were considered.

More research may be necessary to address these hypotheses more accurately.

Logistic regression analyses performed on Rochester study data (Emond et al., 1997) predicted the percentage of children with blood-lead concentrations at or above 10 µg/dL as a function of dust-lead loading and surface type. The results of these analyses are presented in Table 4-2 for carpeted and uncarpeted floors, window sills, and window wells. At low dust-lead loadings, carpeted floors were observed to be associated with a slightly lower predicted percentage compared to uncarpeted floors. However, the difference in percentages between the two surfaces was not considered statistically significant and was virtually zero as the dust-lead loading increased.

Table 4-2. Predicted Percentage of Children With Blood-Lead Concentrations At or Above 10 µg/dL, as a Function of Surface Type and Dust-Lead Loading, Based on Data from the Rochester Study

Carpeted Floors		Uncarpeted Floors		Window Sills		Window Wells	
Dust-lead Loading (µg/ft^2)	% > 10 µg/dL	Dust-lead Loading (µg/ft^2)	% > 10 µg/dL	Dust-lead Loading (µg/ft^2)	% > 10 µg/dL	Dust-lead Loading (µg/ft^2)	% > 10 µg/dL
5	3.8	5	4.3	50	10.1	200	12.3
10	9.9	10	10.2	100	14.8	500	15.3
15	14.7	15	13.5	200	15.6	750	16.5
20	16.6	20	14.9	300	16.2	1500	15.8
25	17.5	25	17.0	400	18.0	3000	17.2
30	18.1	30	18.0	500	18.9	5000	18.3
35	19.2	35	18.9	600	19.5	10000	19.9
40	19.8	40	19.7	700	20.1	20000	20.4

Source: Emond et al., 1997

When measuring dust-lead concentration, some studies reported differences between carpeted and uncarpeted surfaces, but these differences were not necessarily of the nature observed for dust-lead loadings. For example, in baseline measurements taken in the CLEAR study, lead concentrations in carpet-dust tended to be lower than those on uncarpeted floors and window sills, but the difference across surface types was not as great as that for dust-lead loadings (Adgate et al., 1995). Solomon et al., 1976, and Kim et al., 1993, state that higher lead concentrations tend to be found on hard surfaces, while carpeted surfaces tend to have higher lead loadings. This is partially due to less particle movement on carpeted surfaces relative to hard surfaces, as dust becomes trapped among the carpet fibers. As a result, carpets invite increased dust amounts, which generally correspond to lower dust-lead concentrations, while lower dust amounts on hard surfaces are more likely to have higher dust- lead concentrations. On the other hand, Kim et al., 1993, found a highly significant positive correlation (r=0.510) between lead loadings and concentrations in carpet dust.

Roberts et al., 1988, report four major sources of variation in carpet dust accumulation:

- carpet type
- frequency and manner of cleaning
- dust sources (both interior and exterior)
- resident behavior (e.g., cleaning techniques).

In Roberts et al., 1991a, factors selected by a stepwise regression analysis on data from 42 housing units to predict average carpet dust-lead loading in the unit were soil-lead concentration, age of housing unit, and the following yes/no indicators: presence of wood siding outdoors, presence of indoor peeling paint, whether shoes are removed at the door, whether interior remodeling was done in the last 12 years, whether a vacuum with agitator bar is used, whether a walk-off mat is used, and whether the carpet is a flat rug on a bare floor. Roberts et al., 1991a, also claim that households in older units and having one or more of the following characteristics can have carpet dust-lead loadings exceeding 10,000 $\mu g/m^2$ (929 $\mu g/ft^2$): shag rugs, a canister vacuum (with no agitator) or no vacuum, a vacuum with a loose belt or a full dust collection bag, and use of vacuum less than once per week.

When attempts are made to remove dust from carpets, any dust that is not removed from the carpet can eventually become more bioavailable to residents as it is brought closer to the surface. Normal vacuuming tends to remove less than 10% of total lead in an old, contaminated carpet, due to most lead being embedded deep within the carpet (Roberts et al., 1995a; Adgate et al., 1995).

Use of standard commercial vacuums without special filters or bags can increase the number of airborne dust particles, especially those exceeding 0.5 µm in diameter (Dybendal et al., 1991). This effect is heightened in older carpets.

4.2 FURNITURE

As indicated in Chapter 3, the number of published studies investigating the role of furniture, upholstery, or window treatments as indirect sources of lead exposure to children, and efforts to mitigate such exposures, is limited compared to carpets. While studies have reported lead levels in dust on furniture, upholstery, or window treatments, the studies typically do not consider such potential hazards exclusively, but instead may have been designed to evaluate overall lead exposure on various surfaces throughout a house, or to develop an alternative lead measurement procedure. Nevertheless, dust on furniture and curtains, among other items in the home, are recognized as contributing to a resident's total exposure to lead hazards in the home (Roberts, 1997). For example, as was indicated in Section 4.1, "sick building syndrome" has been associated with large amounts of fabric-covered surfaces, including upholstery, relative to the amount of living volume in a house (Raw et al., 1993). Section 5.2 provides detailed information from the encountered studies.

For studies that measured lead levels in furniture, upholstery, and/or window treatments, Table 4-3 summarizes these levels according to study. Included in this table are dust collection methods used, number of dust samples taken, number of housing units sampled, ranges of dust-lead levels (if available), and mean dust-lead level (arithmetic mean for most studies). In general, dust-lead loadings for these surfaces averaged below 100 µg/ft^2. One exception was observed in Al Radady et al., 1994, where net curtains hung and not cleaned for at least one year had average dust-lead loadings of 278 µg/ft^2. As the sample sizes in all of these studies were small, and sampling techniques, sampling locations, and study goals varied considerably from study to study, more information would be necessary to fully characterize potential lead hazards associated with furniture and upholstery.

In some of the studies in Table 4-3, the same types of dust collection methods used to sample dust from carpets were used to sample dust from furniture and upholstery. One study (Roberts et al., 1993) developed a modified HVS3 vacuum sampler to facilitate sampling dust from the light fabric used on upholstery and used this method on used upholstery. However, no field study was encountered which used this method, called the High Volume Furniture Sampler (HVFS). To measure amounts of lead in dust within net curtains, Al Radady et al., 1994, placed the curtains in a 10% nitric acid leaching solution and analyzed the resulting leachate for lead.

One investigation reported certain types of mini-blinds as being a direct source of lead, rather than an indirect source. The Consumer Products Safety Commission (CPSC) found that prolonged exposure to sunlight of foreign-made, vinyl mini-blinds can form lead dust on the surface of the blind if the blind contained added lead as an ingredient (CPSC, 1996). As a result, such blinds should be immediately replaced.

Two studies observed the correlation of dust-lead levels found on furniture with children's blood-lead concentration, and both observed differing results. In the Baltimore R&M study (USEPA, 1996b), the correlation coefficient between blood-lead concentrations and upholstery dust-lead concentrations in upholstery was 0.64, while the correlation between blood-lead concentration and upholstery dust-lead loadings was 0.50. Both of these positive correlations were significant at the 0.05 level. In contrast, Romieu et al., 1995, found no significant correlation at the 0.05 level between furniture dust-lead loading and blood-lead concentration. As the Baltimore R&M study had higher dust-lead and blood-lead levels than in Romieu et al., 1995, used the BRM dust sampler versus the DVM dust sampler, and contained children whose greatest lead exposure threat was via dust, soil, and paint, rather than use of lead-glazed ceramic, conclusions between the two studies can differ for these reasons.

Table 4-3. Summary of Methods Used in Five Studies to Sample Dust from Furniture, Upholstery, and Window Treatments; Numbers of Samples Collected; and Measured Lead Levels

Study/Reference		Dust Sampling Method	Surface Type	# Samples	# Units	Arithmetic Mean (Range in parentheses)	
						Dust-Lead Loading (µg/ft^2)	Dust-Lead Conc. (µg/g)
Roberts et al., 1993		HVFS	Upholstery	10	--	27.8 (2.7-94.9)	229 (130-380)
Baltimore R&M Study (pre-intervention; USEPA, 1996b)		BRM	Upholstery	60	60	37.7[1] (0-657)	423[1] (67-7879)
Romieu et al., 1995		DVM	Furniture	70[2]	200	8.4	
Al Radady et al., 1994		Wipe	Hard furniture	10	1 (new)	6.0	
				10	1 (old)	21.4	
		HNO_3 leaching	Net curtains	6	1 (new)	65.8	
				7	1 (old)	277.9	
Steuteville, 1990	Pre-clean	Vacuum[3]	Upholstery	5	3	28.5 (19.9-34.3)	
	Post-clean	Vacuum[3]	Upholstery	5	3	23.1 (13.7-35.3)	

1 Results reported as geometric means rather than arithmetic means.
2 Only samples with detectable dust-lead loadings.
3 15 L/min air pump

In addition to the significant correlation between furniture dust-lead levels and blood-lead concentration, the Baltimore R&M study also observed significant correlations between furniture dust-lead and other lead exposure variables, such as floor dust-lead and soil-lead. Therefore, the degree of association between upholstery dust-lead and blood-lead concentration, as represented by a positive correlation coefficient, is not necessary the degree to which upholstery dust causes a change in blood-lead concentration. The contribution of furniture or upholstery dust to overall lead exposure relative to other media such as floor-dust and soil was not addressed in the published analyses. The Baltimore R&M study data may have potential for additional analyses to assess whether there is a significant association between furniture or upholstery dust-lead after adjusting for the effects of other household lead exposures, such as floor-dust, sill-dust, soil, paint, etc.

While five articles either investigated methods on mitigating lead exposures associated with furniture, upholstery, and window treatments, or made recommendations on mitigation methods, additional information will be needed to address the mitigation issue to the degree necessary to satisfy the Section 1051 directive. Table 4-4 contains a summary of mitigation approaches encountered in these articles. Typically, conclusions in studies involving new research were based on very few samples collected in very few housing units. As a result, their findings tended to be inconclusive or non-significant (as in Steuteville, 1990). Findings in CH2M Hill, 1991 (as relayed via Ewers et al., 1994) indicate that, on average, a greater percentage of lead can be removed from furniture (18%) versus from carpets (8%) when a procedure of both dry vacuuming and wet cleaning procedures are used.

Table 4-4. Summary of the Issues and Approaches Discussed in the Published Literature on Mitigating Lead Exposures from Furniture, Upholstery, and Window Treatments

Reference	Surface Type	Mitigation Method
Field studies that evaluated certain mitigation methods		
Steuteville, 1990	Upholstered furniture	Three-step procedure: dry vacuum/ wet clean/dry vacuum
Toronto pilot demonstration study (CSC and G&S, 1989)	Upholstered furniture	Dry vacuuming with suction only, or wet cleaning
CH2M Hill (1991) (as reported in Ewers et al, 1994)	Upholstered furniture	Initial vacuuming, followed by three shampooings
Mitigation recommendations (no tests of efficacy of the methods were performed)		
Roberts, 1997	Upholstered furniture	Vacuum or wet wash once a month
	Curtains	Install curtains and furniture that are easy to clean
CPSC, 1996	Mini-blinds (direct exposure source)	Replacement

4.3 AIR DUCTS

As indicated in Chapter 3, only eight documents from seven studies were identified that contained information on lead levels in dust within air ducts and on efforts to mitigate the resulting lead exposure. Furthermore, these studies tended to be either case studies (some of which were conducted in office buildings rather than residences) or to include air duct sampling as only a small portion of the total environmental sampling design. While this section provides an overview of information on air ducts found within these studies, Section 5.3 provides detailed information.

Six of the seven studies provided information on dust-lead levels in air ducts. Table 4-5 presents summaries of these dust-lead levels by study, as well as the dust sampling methods used and sample sizes. Generally, dust-lead loadings in air ducts were very high in these studies, with some samples achieving loadings between 1,000 and 1,000,000 µg/ft^2 prior to any cleaning or abatement efforts. However, most samples had lead loadings between 100 and 100,000 µg/ft^2. The EPA Comprehensive Abatement Performance (CAP) study (USEPA, 1995d; USEPA, 1996a), involving occupied homes assumed to be free of lead-based paint for at least two years, provided the greatest amount of information on lead in dust within air ducts; levels were relatively low in this study compared to the others. In general, air duct dust-lead levels in the Baltimore R&M study (Section 3.1) and the R&R study (USEPA, 1997) were considerably higher than in the CAP study, as these studies included older, vacant units in need of repair and maintenance. Lead contamination in dust in air ducts is not necessary the result of interior sources; studies such as Cram et al., 1986, hypothesize that contaminated outdoor dust can pass through ventilation filters and settle within air ducts. Due to differences in sampling collection methods and other protocol differences, comparison of results across studies such as in Table 4-5 should be made with caution.

The two studies conducted in office buildings (Lovelace et al., 1994; Cram et al., 1986) were the only encountered studies that focused exclusively on air duct contamination. One of these studies (Lovelace et al., 1994) observed that some lead levels in floor dust in living areas adjacent to air ducts were orders of magnitude lower than inside the air ducts.

Only one of these studies (Baltimore R&M Study) investigated the correlations between lead levels (loadings and concentrations) in air ducts and children's blood-lead concentration. While the Pearson correlations calculated in this study were not statistically significant, sample sizes were generally too small to provide sufficient statistical power. Another study (Angle et al., 1995) identified a significant positive correlation (at the 0.05 level) in lead isotope ratios between dust within air ducts and dust on the hands of children.

Two studies (CSC and G&S, 1989; Lovelace et al., 1994) addressed how cleaning of air ducts affected lead levels in dust within them. CSC and G&S, 1989, in its evaluation of household cleaning protocols, found that the recovered dust from air ducts contributed highly to the total lead in recovered dust within a housing unit, but air duct cleaning under the given cleaning protocol did not appear to produce more airborne dust relative to other segments of the cleaning operation. Portions of this cleaning procedure were detailed within the report. The study in Lovelace et al., 1994, indicated that lead levels within air ducts were reduced as a result of cleaning (the cleaning protocols were not presented), but remained high relative to areas outside of the ductwork.

Table 4-5. Summary of Air Duct Dust Sampling Methods Used, Numbers of Samples Collected, and Measured Lead Levels for Six Studies

<table>
<tr><th colspan="2" rowspan="2">Study/Reference</th><th rowspan="2">Sampling Method</th><th rowspan="2"># Samples</th><th rowspan="2"># Bldgs.</th><th colspan="2">Geometric Mean (Range in parentheses)</th></tr>
<tr><th>Dust-Lead Loading (µg/ft^2)</th><th>Dust-Lead Concentration (µg/g)</th></tr>
<tr><td rowspan="2">CAPS</td><td>pilot study (USEPA, 1995d)</td><td>Blue Nozzle</td><td>10</td><td>5</td><td>308
(27-3910)</td><td>749
(363-1699)</td></tr>
<tr><td>full study (USEPA, 1996a)</td><td>CAPS cyclone</td><td>109</td><td>52</td><td>120
(2-40900)</td><td>427
(59-5640)</td></tr>
<tr><td colspan="2">Baltimore R&M Study (pre-intervention; USEPA, 1996b)</td><td>BRM sampler</td><td>29</td><td>29</td><td>59900
(2829-942329)</td><td>1510
(79-11248)</td></tr>
<tr><td colspan="2">R&R Study (USEPA, 1997)</td><td>Wipe</td><td>21</td><td>5</td><td>2900
(205-30900)</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Lovelace et al., 1994</td><td>pre-cleaning</td><td rowspan="2">Wipe</td><td>11</td><td rowspan="2">1</td><td>(71-153000)</td></tr>
<tr><td>post-cleaning</td><td>6</td><td>(145-18000)</td></tr>
<tr><td rowspan="2">Cram et al., 1986</td><td>December</td><td rowspan="2">Brushing</td><td>10</td><td rowspan="2">1</td><td rowspan="3"></td><td>2667
(1428-6550)</td></tr>
<tr><td>April</td><td>10</td><td>1856
(1084-5344)</td></tr>
<tr><td colspan="2">Angle et al., 1995</td><td>Not specified</td><td>21</td><td>21</td><td>383 (arithmetic avg)</td></tr>
</table>

The relative sparsity of published information indicates that many open questions exist on the nature of lead contamination of dust within residential air ducts, how the lead in this dust may come into contact with residents (especially children), how such contact affects blood-lead concentration, and approaches to mitigating such a lead exposure. Nevertheless, evidence exists that air ducts can contain some of the highest levels of lead in dust within a housing unit.

5.0 SUMMARY OF THE LITERATURE REVIEW

This chapter presents detailed information encountered in the literature review on lead exposures associated with carpets, furniture, and forced air ducts. For carpets (Section 5.1), the information is presented within the three research areas of interest: dust collection and measurement techniques, association with blood-lead concentration, and mitigation. For furniture and forced air ducts (Sections 5.2 and 5.3, respectively), the limited number of articles on lead exposures associated with these sources prompted the findings from these articles to be presented by article, rather than within the three research areas. References cited in this chapter are provided in Chapter 6.

5.1 CARPETS

The 59 articles identified in the literature search on dust and lead exposures associated with residential carpet provided information on each of the three research areas of interest: measurement techniques, association with blood-lead concentration, and mitigation. Most of the information addressed measurement issues, including methods to sampling dust from carpets and determining lead levels in carpet-dust. While some information was available to address the association between lead in carpet dust and blood-lead concentration in children, as well as exposure mitigation issues regarding lead in carpets, additional research in these areas is necessary to address remaining questions and data gaps.

Section 5.1.1 provides a summary of procedures used to measure lead levels in carpet dust and information on the efficiency of dust collection using vacuum methods. A discussion of the link between carpet-dust levels and blood-lead concentrations in children is presented in Section 5.1.2. Finally, Section 5.1.3 investigates methods to mitigating the lead hazard associated with carpets and to preventing lead contamination in uncontaminated or abated carpets.

5.1.1 Carpet-Dust Collection and Lead Measurement

Considerable work has been performed to develop dust collection techniques for pesticide and lead monitoring. EPA has recently conducted an extensive literature review on the basic concepts, methods, and strategies for sampling house dust to characterize lead exposures (USEPA, 1995a). This report will cite sources such as USEPA, 1995a, that are relevant to carpet-dust sampling, but will only provide key findings and conclusions from these sources.

5.1.1.1 Dust Sampling/Characterization Methods

Several methods have been developed for characterizing lead levels in dust. Most of these methods involve collecting dust samples and analyzing the samples in the laboratory, while others (e.g., the articles by Bero) attempt to measure dust-lead levels *in situ*. The methods also differ on the extent to which lead is to be measured (e.g., within all dust or only dust that may be bioavailable to humans). Included below are brief discussions on some dust characterization methods that either have been developed specifically to measure lead levels in carpet or have been used to sample dust from carpets in previous studies. Some of these methods may have also been used to sample dust from furniture or air ducts, as cited in Sections 5.2 and 5.3. More detailed discussions on dust sampling methods can be found in the cited references or in USEPA, 1995a.

HVS3/BRM Vacuum Methods

Originally developed for studies to collect house dust for measuring pesticide levels (e.g., Chuang et al., 1995), the high-volume small surface sampler (HVS3; Roberts et al., 1991b) has become an ASTM standard for collecting dust "from carpets or bare floors to be analyzed for lead, pesticides, or other chemical compounds and elements." (ASTM, 1996a). When originally published, the ASTM standard specifically targeted dust sampling from carpeted floors; it was later generalized to apply to any floor surface. The HVS3 is a lighter, simpler version of the HVS2, designed and tested for the EPA as part of the Non-Occupational Exposure Study (NOPES) (Roberts et al., 1988; Roberts et al., 1992). The sampling equipment includes a high-powered upright vacuum cleaner with sampling nozzle, a cyclone that separates particles by size, and a Teflon bottle for collecting the sample. The ASTM standard indicates that for plush, multilevel, or shag carpeting, the HVS3 should operate at 20 cubic feet per minute (9.5 liters per second) through the cyclone, and at 16 cubic feet per minute (7.6 liters per second) on level loop carpeting. The pressure drop across the nozzle and the air flow are monitored and controlled to assure uniform sampling conditions from sample to sample.

When spiking carpets with dust ($\leq$150µm) using techniques documented in ASTM, 1996b, and when operating the HVS3 under the flow rates specified in ASTM, 1996a, dust collection efficiency of the HVS3 was measured as 66.8% on level loop carpeting and 69.5% on plush carpeting (Roberts et al., 1991b; ASTM, 1996a). The HVS3 cyclone catch bottle retained more than 99.8% of collected lead.

A modified, portable version of the HVS3 was developed for the Baltimore R&M study (USEPA, 1996b; Farfel et al., 1994). This version replaces the upright vacuum with a portable, hand-held vacuum (the same vacuum model used in the CAPS cyclone as described below; USEPA, 1995b). This version is known as the BRM vacuum sampler (named after this study) and was used in this study to collect dust samples from carpeted surfaces, among others. The BRM sampler was compared with the DVM and wipe sampling methods in the Rochester Lead-in-Dust study (Lanphear et al., 1995; The Rochester School of Medicine and NCLSH, 1995) and with the Blue Nozzle vacuum and CAPS cyclone (relative to dust and lead recoveries) in a laboratory study. See Section 5.1.1.2 for details on these evaluations.

Microvacuum Method (MVM, or DVM)

The microvacuum method for dust collection was developed by researchers at the University of Cincinnati for studies that characterize pathways of lead from environmental media to blood (Que Hee et al., 1985). In EPA studies, this method is more prominently known as the Cincinnati DVM ("dust vacuum method"), and so will be denoted as such in this report (USEPA, 1995a). This method has been used frequently in studies measuring dust-lead in carpets and blood-lead concentration (e.g., Ewers et al., 1994; Romieu et al., 1995).

In addressing the hand-to-mouth route of lead ingestion that is common among young children, the developers of the DVM were interested in collecting only dust that is most available to come in contact with the hands of children. The DVM sampler consists of a portable personal air sampling pump operated at 2.5 to 3 liters per minute (USEPA, 1995a) that collects dust into a three-piece air sampling cassette. It has been used in several epidemiological studies as it "has been shown to produce results that correlate with exposure as measured by blood lead" (Ewers et al., 1994). Other advantages include its consistent lead recoveries across a variety of surfaces (including carpets), its portability and lightweight property, its ease of use, and its ability to operate without household electricity (Clark et al., 1995). One disadvantage is the need to ensure that dust or other material does not clog the nozzle (USEPA, 1995a).

In sampling carpet dust, the DVM tends to collect only the surface dust that is more readily available to children (generally particles less than 250 µm in diameter), and not the more deeply-embedded dust in the carpet. On average, the DVM removes only about 1% of the lead dust in carpets that would typically be removed if an industrial quality HEPA vacuum was used at a rate of 10 min/m^2 (Ewers et al., 1994; Clark et al., 1996).

At a sampling velocity of 2 l/min on loose dust less than 149 µm (i.e., dust most likely to adhere to a child's hand), sampling efficiencies of the DVM after one iteration of the sampling process were 64% for indoor-outdoor carpeting and 42% for shag plush pile carpeting, compared to an average of 63% across all surfaces tested (wood, linoleum, carpeting) (Que Hee et al., 1985). These efficiencies increased to 79% for indoor-outdoor carpeting and 66% for shag plush pile carpeting (and 80% across all surfaces tested) after two iterations. More discussion of the DVM's sampling efficiency on carpets is presented in Section 5.1.1.4.

The DVM sampler was among three dust sampling methods evaluated in the Rochester Lead-in-Dust study (Lanphear et al., 1995; The Rochester School of Medicine and NCLSH, 1995); see Section 5.1.1.2 for details.

CLEAR Study Vacuum

A vacuum method was developed to collect dust samples from carpets in the CLEAR Study (Section 3.1; Wang et al., 1995; USEPA, 1995a). This vacuum is a modified Data Vac II (canister) vacuum cleaner with in-line, cone-shaped filter. The vacuum's nozzle inlet is jagged, rather than flat, to increase air flow for lifting dust from carpets more easily, and to allow the inlet to move carpet fibers so that particles buried within the fibers can be captured. The size of the nozzle inlet "teeth" can be varied to accommodate different carpet fiber lengths. The vacuum's flow rate is approximately 28 liters per second.

Wang et al., 1995, conducted a laboratory study to investigate factors influencing the collection efficiency of the CLEAR Study vacuum sampler on carpets. When varying relative humidity, carpet type, vacuum velocity, and total dust-lead loading in the carpet, the collection efficiency ranged from 38% to 89%. Further results of this investigation are presented in Section 5.1.1.4.

Blue Nozzle Vacuum Method (and modifications)

The Blue Nozzle vacuum consists of a Gast rotary vane pump connected via Tygon tubing to the same filter and cassette used in the DVM (USEPA, 1995a) The vacuum is named for the blue color of its pick-up nozzle. Its sampling flow rate is 16 liters per minute (USEPA, 1995a). It was used in 1989-1990 to collect dust samples from various surfaces, including carpets, within the HUD National Survey of Lead-Based Paint in Housing (USEPA, 1995c; Table 4-1 of Chapter 4). However, when it was used in 1991 within the pilot phase of EPA's Comprehensive Abatement Performance Study (USEPA, 1995d), its limitations in dust collection efficiency and nozzle versatility were recognized, prompting research into modifications to the vacuum. In a methods development study (MRI, 1992; Lim et al., 1995), the dust collection efficiency of the Blue Nozzle vacuum was characterized for a number of surfaces, including carpets. Dust collection efficiency was defined as the difference in the cassette weight after use versus before use, divided by the weight of the composite dust applied to the surface. For samples of differing particle sizes, the Blue Nozzle dust collection efficiency on carpets ranged from 7.8% to 12.3%. When the particle size was less than 250 µm, the efficiency percentage for carpet was much lower than that for other surfaces (concrete, wood, linoleum), primarily due to the dust particles embedding themselves within the carpet fibers. However, efficiency percentages for the other surfaces did not exceed 60% at such low particle sizes. For larger particle sizes, the efficiency percentages for all surfaces were in the 10-20% range.

In the methods development study (MRI, 1992; Lim et al., 1995), one modification of the Blue Nozzle vacuum consisted of an in-line dust collector using a 37-mm cassette with a preloaded 0.8 µm, cellulose-ester membrane. It operated with twice the airflow as the Blue Nozzle vacuum. Across all particle sizes, the dust collection efficiency with this modified vacuum exceeded 85% for wood, linoleum, and concrete, while the efficiency ranged from 50% to 65% for carpets, which was considered significantly lower than the others. While its lifting velocity was higher than that of the Blue Nozzle vacuum, it was not sufficient to collect particles embedded in carpet fibers (MRI, 1992). In addition, the inlet opening of the 0.5" nozzle was considered too small to collect a dust sample from a 1 ft^2 in two minutes or less.

The above methods development study also developed and evaluated the CAPS cyclone (below). Additional details are found in MRI, 1992, and Lim et al., 1995.

In a laboratory study, the Blue Nozzle vacuum was compared with the BRM sampler and the CAPS cyclone relative to their dust and lead recoveries. See Section 5.1.1.2 for details on this evaluation.

CAPS Cyclone Method

As discussed above, the CAPS cyclone was developed in a laboratory study to identify a dust collection method for the Comprehensive Abatement Performance Study (CAPS) which improves the dust collection efficiency and nozzle limitations associated with the Blue Nozzle vacuum (MRI, 1992; Lim et al., 1995). The CAPS cyclone consists of a cyclone collector on which the filter cassette holder plug is screwed. The cyclone is connected to a commercially-available hand-held vacuum (Dirt Devil® Model #103) and uses a 1" nozzle inlet. In this laboratory study, dust collection efficiencies for the CAPS cyclone exceeded 90% for all tested surfaces (concrete, linoleum, wood, carpets) when the dust particle size exceeded 250 µm. While dust collection efficiencies continued to exceed 90% for concrete, linoleum, and wood when particle sizes were below 250 µm, the efficiency percentage associated with carpets ranged only from 74% to 78% (MRI, 1992; Lim et al., 1995). As carpets were not sampled in the CAPS, no field data on lead in carpet-dust samples collected using the CAPS cyclone have been encountered.

In a laboratory study, the CAPS cyclone was compared with the BRM sampler and the Blue Nozzle vacuum relative to their dust and lead recoveries. See Section 5.1.1.2 for details on this evaluation.

Solomon and Hartford Vacuum Method

This vacuum method is documented in Solomon et al., 1976. A portable vacuum pump with a nylon filter holder was used to collect and trap dust. The used filter and dust was then placed in tared glassene envelopes for shipment to the laboratory. When the vacuum was used to collect two samples of dust from the same area (to investigate sampling efficiency), approximately 90% of the total lead collected was obtained in the first sweep.

Dislodgeable Dust Methods

Various types of non-vacuum, dislodgeable surface dust collection methods have been developed, primarily to support studies investigating pesticide contamination in carpets. These methods are relevant for sampling surface dust which can come into direct contact with children playing on the carpet. One such method involves pressing a bare hand on a carpet in a prescribed manner at a given pressure, then rinsing the hand to remove and collect the dust (USEPA, 1995a). A second method involves placing a moistened polyurethane foam (PUF) cover on a weighted roller, and rolling the roller across a specified area of carpet (Lewis et al., 1994; USEPA, 1995a). The PUF roller simulates a 9 kg child crawling on the carpet. Both methods were used in the EPA House Dust/Infant Pesticides Exposure Study (HIPES) (Fortmann et al., 1991b). Roberts et al., 1989, have developed a cotton glove press test as a surrogate to requiring direct hand contact to dust. The cotton gloves can be digested in the laboratory, similar to dust wipes. The cotton glove press test was used in the Non-Occupational Exposure Study.

The only indication that the dislodgeable dust methods in the previous paragraph have been applied in a field study to evaluate lead exposure was in an EPA nine-home lead study conducted in 1991 (USEPA, 1995a). No information on this study was available.

Wipe collection methods

Wipe dust collection methods, which collect dust from a surface by wiping the surface with a premoistened digestible wipe, are primarily meant to be used on smooth surfaces. As it can be difficult to use wipe methods to obtain dust embedded within the carpet fibers and deep in the carpet, and because dust-lead concentrations cannot be determined from wipe dust samples, many researchers prefer to use vacuum methods to collect dust from carpets. However, some studies which used exclusively wipe techniques for sampling dust occasionally needed to take dust samples from carpeted surfaces. In other studies, such as the Rochester Lead-in-Dust study (Lanphear et al., 1995; The Rochester School of Medicine and NCLSH, 1995), the wipe method was used in a comparison with the BRM and DVM vacuum methods; results are found in Section 5.1.1.2.

HUD interim clearance standards on lead in dust are expressed in terms of dust-lead loadings assuming a wipe dust collection technique. Health-based standards on lead in dust to be set in response to Section 403 will also be expressed in this manner. Therefore, wipe techniques remain an important dust collection procedure for clearance purposes. However, it is currently unclear how to obtain such standards for carpeted surfaces, partially due to the problems associated with taking wipe dust samples from carpet.

Commercial vacuum collection methods

Smaller studies, studies conducted in Europe, and studies in smelter areas have used commercial vacuum cleaners to collect house dust, rather than laboratory-developed vacuum dust collection methods. Typically, grab samples of dust from the vacuum cleaner bag are obtained for laboratory analysis when using commercial vacuum cleaners. Studies such as Davies et al., 1987, have utilized this approach (among possibly other approaches) for collecting dust samples. Methods development and characterization studies, such as Que Hee et al., 1985, and Wang et al., 1995, have used grab sampling from residential commercial vacuums to obtain household dust for laboratory studies.

When the dust sample collection procedure utilizes commercial vacuums owned by the household, the study cannot control the efficiency of the sampling process attributed to the sampling device (Roberts et al., 1988). In addition, while dust in residential vacuum bags represents an average dust characterization across the housing unit, it is not guaranteed to represent only carpet or only areas which children frequent, and a dust-lead loading cannot be estimated from a grab sample. As a result, grab sampling from household vacuums not precharacterized in the laboratory is often not the sole means of collecting dust for household dust-lead characterization analysis.

In a laboratory study, dust and lead recoveries associated with carpets were investigated for certain commercial vacuums. See Section 5.1.1.2 for details on this evaluation.

X-Ray Fluorescence (XRF) methods

Unlike the dust collection methods cited above, Bero et al., 1993, and Bero et al., 1995b, have developed a procedure for measuring total lead loadings in carpet that do not require collecting and analyzing dust samples. This procedure uses an XRF testing approach, which is a standard technique for measuring lead levels in paint and has been used to measure lead levels in other media such as soil. The XRF method provides immediate measurements without the need and corresponding expense for sample preparation, extraction, and analysis. As this method does not involve a dust sampling stage, thereby eliminating the problem of low sampling efficiencies, it is able to estimate total lead loading in the carpet. Once total loadings can be measured, standards and cleanup criteria for lead loadings in carpets can be developed as for uncarpeted floors.

The XRF testing methods were developed in two laboratory studies. These studies considered four types of carpeting: high-quality nylon plush, medium-quality berber, lower-quality nylon plush, and lower-quality nylon sculptured. In each study, lead-contaminated soil at one of a variety of loading levels was added to the carpet and embedded into the fibers (ASTM, 1996b). Each study used a different approach to testing on 5 cm^2 carpet swatches:

Study #1: Five measurements of two minutes each in different spots on the swatch
Study #2: Twenty measurements of 45 seconds each in different spots on the swatch.

The first approach was also able to detect soil-lead concentrations in carpet within range of the current soil-lead action levels of 500 to 1000 µg/g. The second approach was established to reduce within-swatch variation and reduce detection limits associated with the first approach.

Bero's research has focused solely on determining lead levels in soil within carpeting and has not considered lead-contaminated housedust. No approved field protocol has been established for this approach, nor has analysis been performed on worn carpets. While the XRF method allows lead loading measurements to be obtained while in the field, it is uncertain how recommended test durations would limit the number of tests that could be performed.

Freeze fracture carpet grinding method

This technique was used at the Bunker Hill Superfund Site in Kellogg, Idaho, to evaluate techniques for remediating lead exposures in carpet and furniture. Its goal is to determine the total lead loading within a carpet or other soft surface (Bero et al., 1996). In this procedure, a carpet sample is frozen within a beaker (using liquid nitrogen), ground in a Wiley mill, then chemically digested and analyzed. Therefore, the entire carpet sample is analyzed, rather than the dust which could be removed from the carpet, removing any dust recovery bias. However, a procedure for determining locations for taking carpet samples is still necessary, and the result is destructive to the carpet.

Laboratory evaluation of this procedure (Bero et al., 1996) involved spiking samples of three types of carpets with differing amounts of lead and conducting the procedure to measure the amounts of lead in the samples. Results showed that approximately 67% of the total lead spiked within the samples was recovered by this method. Material losses could occur during sample handling, and portions of the sample may be retained on the beaker and mill during the grinding process. Therefore, Bero et al., 1996, indicate that additional efforts are needed to develop proper sampling protocols and quality control procedures for conducting this technique.

5.1.1.2 Comparing Dust Collection Methods Based on Performance

Two studies have been identified which used different approaches and criteria for comparing the performance of competing dust collection methods. Their conclusions in regard to sampling from carpeted surfaces are presented here. The first study is an EPA-sponsored study which compared methods according to their dust recoveries and lead recoveries in a laboratory setting (USEPA, 1995b). The second study is the Rochester Lead-in-Dust study, which used three approaches to evaluate performance: measuring correlation with children's blood-lead concentration in a field setting, measuring lead recovery in a laboratory setting, and measuring the extent of measurement error associated with dust-lead levels.

USEPA, 1995b

As competing dust collection methods can differ in their overall performance and in the amount and type of dust collected, proper interpretation of the analytical results of dust samples must take these methodological differences into account. EPA has recently conducted a laboratory evaluation of specific dust sampling methods (USEPA, 1995b). In this evaluation, the dust and lead recoveries of three laboratory-developed vacuum sampling methods (the Blue Nozzle vacuum, the CAPS cyclone, and the BRM sampler), one wipe sampling method, and four household vacuum cleaners with beater bar attachments, were measured for a number of dust particle sizes. Carpet, both unspiked and spiked with dust, were among the substrates for which dust recoveries were obtained in this laboratory study. Other substrates included upholstery, wood, and vinyl. The wipe sampling method was not used on carpets.

No significant difference in dust recovery (weight of collected dust divided by weight of dust deposited on the substrate) was observed among the substrates for the three laboratory-developed vacuum sampling methods. Across substrates (including carpet), average dust recovery was 30% for the Blue Nozzle vacuum, 84% for the CAPS cyclone, and 89% for the BRM sampler. Particle size played a significant role in dust recovery, with large particle size associated with lower recoveries for the Blue Nozzle and with higher recoveries for the CAPS cyclone and the BRM sampler.

Similar conclusions between these three vacuum methods were observed when evaluating lead recoveries (weight of collected lead divided by weight of lead deposited on the substrate). Sampler type, dust particle size, and dust loading were significant factors on lead recovery, while substrate was not a significant factor. Across substrates (including carpet), average lead recovery was 26% for the Blue Nozzle vacuum, 72% for the CAPS cyclone, and 81% for the BRM sampler.

For the commercial vacuum cleaners, dust recovery percentages were lowest among carpeted surfaces; only 76% of dust was recovered from carpets spiked with dust and 79% for other carpets, compared to a maximum observed recovery of 93% for wood surfaces. The study concluded that, on average and across all surface types, approximately 75% of carpet dust can be collected when using a vacuum with beater bar attachment, with lead recovery similar to dust recovery on a relative basis. Variation from this average is expected across different vacuum designs and the extent to which the dust is ground into the surface.

Lead recovery for commercial vacuum cleaners, defined as the product of lead concentration in dust shaken from the vacuum bag and the weight of recovered dust, divided by the weight of lead applied to the substrate, exceeded 100% for carpets in all but one of the four tested vacuums. One reason for observing recoveries that exceed 100% is that higher lead concentrations are expected to exist in dust removed from the bag compared to dust remaining within the bag. This would imply that lead particles are less likely to adhere to the bag than dust particles, on a weight basis. Across all substrates tested in this study, lead concentrations in dust obtained from commercial vacuum cleaner bags were approximately 12% higher than lead concentrations within the dust placed on the substrate.

Further discussion of factors found to influence dust collection recovery are presented in Section 5.1.1.4.

The Rochester Lead-in-Dust Study

One objective of the Rochester Lead-in-Dust study (Section 3.1) was to evaluate three alternative dust collection methods in terms of the correlation between dust-lead measurement and the blood-lead concentrations of resident children. The BRM sampler, the DVM sampler, and wipe methods were used to collect side-by-side dust samples from carpeted floors, uncarpeted floors, window sills, and window wells in various rooms within the 205 study units. Geometric mean dust-lead loadings and dust-lead concentrations (when applicable), along with estimated variability in these geometric means, are presented in Table 5-1.

Table 5-1. Geometric Mean Carpet Dust-Lead Measurements (±2 SD) Under Each Dust Collection Method, As Measured in the

Rochester Lead-in-Dust Study[1]

Measurement Type	BRM	DVM	Wipe
Dust-Lead Loadings ($\mu g/ft^2$)	187 (10, 3395)	3 (0, 62)	11 (2, 75)
Dust-Lead Concentrations ($\mu g/g$)	242 (31, 1916)	226 (24, 2135)	--

Source: Lanphear et al., 1995
[1] The intervals in this table are the exponentiation of the mean ± 2 standard deviations of log-transformed dust-lead measurements, calculated across housing units.

The children in this study (12-31 months of age) had a geometric blood-lead concentration of 7.7 µg/dL. While the correlation with blood-lead concentration was statistically significant for all dust collection methods, with dust-lead loading having higher correlations than dust-lead concentration, dust-lead measurements associated with BRM and wipe collection methods had higher correlations than those associated with the DVM sampler (Lanphear et al., 1995). More detail on these results is presented in Section 5.1.2.

In 20 of the 205 housing units, additional side-by-side dust samples were collected to assess measurement error associated with the dust collection methods (Emond et al., 1997). Among the surfaces sampled (hard floors, carpeted floors, window sills and wells), measurement error tended to be lowest for carpeted floors; this finding was consistent for each dust collection method and for both loadings and concentrations. However, when assessing the extent of repeatability in measurements among side-by-side carpet dust samples, the correlation of repeated DVM dust-lead concentrations was not significantly different from zero. The magnitude of measurement error relative to the measurement range was also characterized by calculating reliability ratios (Emond et al., 1997); ratios close to one implied small measurement error. While carpeted floors generally had among the highest reliability ratios across surface types for a given collection method, the reliability ratios associated with carpeted surfaces were generally higher under the wipe and BRM methods compared to the DVM, and for dust-lead loadings compared to dust-lead concentrations for a given vacuum method.

A second phase of the Rochester study involved a laboratory analysis to characterize the error in dust-lead measurements (Emond et al., 1997). Dust with known lead levels were spiked onto one of three surfaces (carpet, linoleum, wood) and collected using one of the three methods used in the field study (BRM, DVM, wipe). Based on three tests per method performed on carpets, the BRM had a much higher mean recovery percentage of lead (95.2%) compared to the wipe (24.4%) and the DVM (31.4%). The variability associated with the lead recovery percentage on carpet was lowest for the BRM, indicating that the BRM collected consistently high percentages of total lead from carpets, while the DVM had the highest variability. For all methods, variability in lead recovery percentage was highest for carpets compared to linoleum and wood.

5.1.1.3 Factors Influencing Dust and Lead Levels in Carpet

A study of 120 housing units in eight suburbs around Christchurch, New Zealand (Kim et al., 1993), indicated that carpet wear (coded as 0, 1, 2, or 3, with 0=new and 3=threadbare) was the most significant factor associated with "dustiness" (or dust loading) associated with the carpet in the main living area of the unit. In turn, the study found that carpet "dustiness" had a highly significant positive association with lead loading, but not lead concentration. This study used the vacuum dust collection method documented in Solomon et al., 1976. The average amount of dust in carpets increased ten-fold from new to threadbare carpets (69.5-728 mg/m^2, or 6,500-68,000 µg/ft^2), while lead concentration showed only a modest increase. Presence of lead-based paint and traffic density were significant factors on carpet dust-lead concentration, which had a geometric mean of 573 µg/g across units in this study. Other potentially important factors included the existence of a fireplace, a galvanized roof, and house age. In noting that higher lead concentrations are found in lead-contaminated dust with smaller particle sizes, the authors hypothesize that increased carpet wear is associated with an increase in the proportion of carpet dust represented by fine particle sizes.

In an EPA-sponsored study of nine housing units in North Carolina (Fortmann et al., 1991a; Roberts et al., 1992), correlations were reported between lead levels in carpets and lead in other media. Carpet dust-lead concentrations ranged from 77 µg/g to 1,900 µg/g across housing units, while carpet dust loadings ranged from 12 - 4,800 µg/m^2 (1.1 - 446 µg/ft^2). Lead concentrations and lead loadings in carpet dust were significantly correlated (r=0.82). Significant correlations (at the 0.05 level) were observed between carpet dust-lead concentrations and the following: house age (r=0.83), entryway dust-lead concentration (r=0.83), soil-lead concentrations at the dripline (r=0.82) and in the yard (r=0.82), and lead levels in interior paint (r=0.76). Significant correlations (at the 0.05 level) were observed between carpet dust-lead loadings and the following: soil-lead concentrations at the dripline (r=0.72) and in the yard (r=0.73), and lead levels in interior paint (r=0.71).

Roberts, 1997, indicates that remodeling and paint removal efforts in units containing lead-based paint can increase lead loadings in carpet dust by a factor of two to four. In addition, these factors contribute to an estimated three percent increase in loadings with the age of the housing unit.

Al-Radady et al., 1994, performed a small study investigating how time plays a factor in determining dust and lead loadings in carpets within a housing unit. Within each of four houses, dust samples were collected within six consecutive sampling iterations from each of three sections of carpet using an adapted Philips P60 vacuum cleaner (the same adaptation used by Davies et al., 1987). While dust loadings generally declined with each sampling iteration, lead loadings were relatively constant or increased slightly over the iterations within each house. In one house, additional carpet-dust samples were collected once per month from July to December. Higher lead-loadings were associated with samples collected in the cooler, wetter months. This finding, along with the finding that carpet dust-lead loadings decline as distance from the entryway increases in this house, allowed the authors to conclude that lead contamination of carpets was primarily the result of easier tracking of soils into the house in wet months. However, the authors did not consider the possibility of lower dust-sampling efficiencies in months with low relative humidity, as was observed in studies documented in Section 5.1.1.4.

Leese et al., 1997, investigated the relationship between dust present on carpeted surfaces and airborne dust in an office building. The HVS3 was used to sample dust from carpets, while a fine particle sampler was used to sample airborne dust. A negative correlation, which was significant at the 0.05 level, was observed between dust levels in carpets and airborne dust levels. Levels of carpet-dust increase as airborne dust leaves the air and settles on the carpet. In turn, as carpet-dust is disturbed, dust leaves the carpet and becomes airborne. No consideration was made in this study as to lead levels in this dust.

Studies have also been performed to identify significant factors associated with the amount of dust and lead that is introduced to otherwise clean or decontaminated carpets within a housing unit. Results of these studies are presented in Section 5.1.3.2.

5.1.1.4 Factors Influencing Carpet-Dust Collection Efficiency

A number of studies have investigated carpet dust collection efficiency in order to properly interpret results of lead characterization studies involving dust collection techniques. Several of these studies specifically address collection efficiency from carpeted surfaces. Studies have identified the following factors as among those significantly associated with dust collection efficiency for particular collection devices:

- carpet type
- relative humidity
- vacuum particle lifting velocity
- dust particle size
- magnitude of static pressure in the vacuum nozzle
- presence of agitator bars on the vacuum

More details on the conclusions of these studies are presented in this subsection.

In the laboratory study in which the CAPS cyclone was developed and evaluated (MRI, 1992; Lim et al., 1995), low dust sampling efficiencies were observed for carpets when spiked with dust having small particle sizes, due to the small particles embedding within the carpet fibers. Vacuums having higher particle lifting velocity settings had improved dust collection efficiencies.

A laboratory study was conducted to investigate the effect of four factors on the efficiency of the CLEAR Study vacuum in sampling dust from new carpets (Wang et al., 1995). These four factors were type of carpet (level loop vs. shag), vacuum sampling velocity (10.5, 13.5, and 27 m/sec), relative humidity (20%, 60%, 85%), and dust loading spiked into the carpet (8.0, 16.0, 24.0 g/m^2). Efficiency was reduced by as much as 30% for shag carpeting compared to level loop carpeting, as shag carpeting's longer fibers more easily retain dust particles. Vacuum velocity had a significant effect on collection efficiency for shag carpeting, but not on level loop carpeting. Effects due to amount of dust spiked into the carpet supported the statements from other studies that collection efficiency declines when very high dust loadings exist within the carpet.

The vacuum efficiency study in Wang et al., 1995, concluded that lower values of relative humidity were also associated with lower efficiencies in the CLEAR Study vacuum, as the electrostatic field between the carpet and dust particles is more intense with lower humidity. The effect of low relative humidity was more pronounced in the presence of shag carpeting, where the average efficiency dropped from 68% to 52% when relative humidity dropped from 60% to 20%, compared to a drop from 74.7% to 72.9% in average efficiency on level-loop carpet. The effect of relative humidity decreased as the values of relative humidity reached 40%, indicating that the efficiency of carpet dust collection has seasonal effects (i.e., low indoor relative humidities occur in colder months). If this result also holds for other collection methods, this may partially explain why some studies have observed higher dust-lead loadings in summer months. Evidence exists that when conditions exist where low vacuum efficiencies are expected, increasing the vacuum velocity will improve the efficiency reduction. Finally, as also seen in other studies, collection efficiencies reduce as the dust loading within the carpet increases.

For the DVM, Que Hee et al., 1985, observed that statistically significant differences in sampling efficiencies occurred between two sampling velocities (2 vs. 20 L/min) after one iteration of the dust sampling process on shag rugs. The efficiencies equaled 42% and 54% for the low and high velocities, respectively, and were lowest among seven different types of surfaces sampled (e.g., wood board, linoleum). Cumulative efficiencies across sampling iterations on a shag rug surface did not exceed 90% for either velocity until four iterations were completed.

In tests to develop the HVS2 vacuum method (Roberts et al., 1988), sampling efficiencies of dust particles less than 150 µm reached 30% for carpets, compared to 93% for uncarpeted surfaces. This efficiency was 24% ±4% on level loop carpeting and 10.2%±0.5% on plush carpeting. Increasing the volumetric flow and the magnitude of static pressure in the vacuum nozzle were found to considerably increase the collection efficiency of fine dust particles on level loop carpets, but not on plush carpets. In contrast, the loading of dust on the carpet did not significantly affect the sampling efficiencies for either carpet type.

Wang et al., 1995, also point out that if vacuum collection efficiency is overestimated, the surface dust-lead loading will be underestimated. In addition, the same amount of dust collected under different conditions that can affect vacuum efficiency can lead to different dust loadings.

Bero et al., 1995a, are among the authors that report vacuum dust sampling efficiencies being a function of carpet type. In laboratory studies conducted by the authors, it was more difficult to spike soil deeply into thick, plush carpeting than in lower-grade carpeting. This can contribute to higher sampling efficiencies for thicker carpeting.

Roberts et al., 1991a, have reported how vacuum efficiencies can vary between vacuums with power-driven agitator bars and canister vacuums (with no agitator). Vacuums with agitator bars can collect from two to six times as much dust than a canister vacuum, with higher efficiencies associated with plush and level loop rugs. On average, vacuums with agitator bars are reported to collect from 10% to 12% of dust from shag rugs, from 35% to 55% of dust from plush rugs, and from 70% to 80% of dust from flat rugs, compared to canister vacuums which collect an average of only 4% of dust from shag rugs, 10% of dust from plush rugs, and from 40% to 50% of dust from flat rugs (Roberts et al., 1988).

While conventional and canister vacuums have been used to collect dust samples, Roberts et al., 1988, indicate that recoveries of fine materials can be quite low for these vacuums. Fine materials, which can contain the highest lead concentrations, can adhere to the bags, canisters, and collection nozzles.

Hilts et al., 1995, cites that HEPA vacuums retain all but 0.03% of dust particulates greater than 0.3 µm. In contrast, household vacuums with filter bags consistently fail to retain dust particulates of less than 5 µm. As indicated in Johnson et al., 1982, particulates in the lowest size fraction typically have high lead concentration if household dust is lead-contaminated.

5.1.2 Association Between Lead in Carpet-Dust and Blood-Lead Concentration in Children

A study by Dolcourt et al., 1978, was one of the first to highlight a potential link between carpet dust-lead levels and elevated blood-lead concentrations (although the study did not use statistical methods to substantiate such a link). This study indicated that carpet dust samples (collected via "suction on preweighed glass filters") from units with children having elevated blood-lead concentrations had very high lead concentrations. Six units containing ten children with blood-lead concentrations exceeding 40 µg/dL had average carpet dust-lead concentrations ranging from 1,701 µg/g to 17,567 µg/g. Five of these six units were in rural areas, while no unit contained contaminated water or paint, and at least one parent worked in lead-related industries. As carpet-lead concentrations were highest in clothes closets, dustfall from parents' work clothing was considered a major factor in carpet contamination.

Later studies used such statistical techniques as correlation analysis and regression methods to quantify the nature of the association between blood-lead concentration and a number of possible predictors, including dust-lead levels. The following studies encountered in the literature search provided information on the association between carpet-dust lead and children's blood-lead:

Davies et al., 1990
Clark et al., 1996
Clark et al., 1995
Hilts et al., 1995
Rochester Lead-in-Dust study (Lanphear et al., 1995; Emond et al., 1997; The Rochester School of Medicine and NCLSH, 1995; Hartford et al., 1996)
Cambra et al., 1995
Romieu et al., 1995

Only the two studies by Clark et al., and the Rochester study, were conducted in the United States.

The overall conclusion from these studies is that lead levels in carpet dust (under a variety of dust collection techniques) tend to have a significant positive correlation with children's blood-lead concentration, with dust-lead loading having a higher correlation than dust-lead concentration. However, the direct effect of lead in carpet dust on blood-lead concentration is reduced when taking into account other factors such as mouthing behavior, socioeconomic status, and lead levels in other media. There is also evidence that a health-based standard for dust-lead loadings in carpets may need to be lower than that for uncarpeted floors, although such a conclusion remains preliminary. The findings presented within these articles are now presented.

Davies et al., 1990

Roberts et al., 1991b, cites this study conducted in the United Kingdom (U.K.) when stating, "the mass loading of Pb found in a carpet appears to be the best single predictor of the blood Pb of a toddler." According to Roberts et al., 1992, this study found that dust-lead loading in the carpet within a child's play area has a higher correlation with blood-lead concentration in two-year olds (r=0.46) than does dust-lead concentration (r=0.21) or hand-lead loading (r=0.34). In turn, hand-lead loading was more highly correlated with dust-lead loading (r=0.44) than dust-lead concentration (r=0.24), implying that dust-lead loading in this study was a better predictor of lead exposure to children with frequent mouthing tendencies than concentration. Both dust-lead loadings and blood-lead concentrations in this study averaged near the estimated national averages for the U.K. The dust sampling method in the Davies study is an adapted Electrolux 350 vacuum cleaner (Davies et al., 1987). However, a review of Davies et al., 1990, could not verify that only carpeted surfaces were sampled in their study.

Clark et al., 1996

This study was a first attempt at determining whether the HUD interim standard of 100 µg/ft^2 for uncarpeted floors was relevant for carpeted floors from a health perspective. Data from the Cincinnati portion of the EPA Urban Soil Lead Abatement Demonstration Project were used in this data analysis. In this study, venous blood samples were collected from participating children (aged 6 to 72 months), and a composite floor dust sample was collected using DVM techniques from one square foot subareas in the following three rooms in their residences: the child's bedroom, the room most often used by the child (other than the bedroom), and the interior entryway. The analysis involved data for 23 housing units built in the 19th century, which had been rehabilitated nearly 20 years earlier to remove most lead-based paint hazards, and where all floor dust samples in the study were collected from carpeted surfaces. Only data for blood and dust samples collected in 1990 prior to any dust or soil lead abatement conducted in the study were used in this analysis. Descriptive statistics of blood-lead and dust-lead levels are provided in Table 5-2.

Table 5-2. Descriptive Statistics of Blood-Lead and Carpet Dust-Lead Data from Clark et al., 1996

(n=23)	Geometric Mean	Geometric S.D.	Minimum	Maximum
Blood-lead conc. (µg/dL)	7.1	1.9	1.8	20.8
Carpet dust-lead loading (µg/ft^2)	6.2	0.43	0.61	161.
Carpet dust-lead conc. (µg/g)	244.	2.6	15.	1030.

The authors define a criterion for setting a post-abatement clearance level for lead as that level for which no more than five percent of the children exposed at that level would be expected to have a blood-lead concentration at or above 10 µg/dL. As a result, they performed a linear regression on data for the above 23 housing units to predict blood-lead concentration as a function of dust-lead loading. Under this regression, the dust-lead loading at which 10 µg/dL was the 95th percentile of the predicted blood-lead concentration was 11.5 µg/ft^2. This is considerably below the HUD interim standard of 100 µg/ft^2 for uncarpeted floors, thereby suggesting that the clearance level for carpeted floors should be lower than this interim standard, implying a lower clearance level for carpeted floors versus uncarpeted floors.

After taking logarithms of the data, blood-lead concentration was found to correlate significantly with carpet dust-lead loading (correlation of 0.52, p=0.01). In contrast, the correlation between blood-lead concentration and dust-lead concentration was not significant at the 0.05 level.

In interpreting the findings of this data analysis, the following caveats should be considered:

- Results are based on a small amount of data from a single locale. Additional data from other areas of the country would be needed to more accurately estimate an appropriate clearance level.

- If the criterion defined by the authors were to be applied to data from uncarpeted floors, it is possible that the resulting clearance level would also be below the HUD interim standard of 100 µg/ft^2, implying that carpeted and uncarpeted surfaces would not differ as greatly in their associated clearance levels. (Some evidence of this possibility is found in Clark et al., 1995.)

- The HUD interim standard is based on wipe collection methods, while the dust-lead loadings in this analysis were based on DVM methods. Thus, the clearance level of 11.5 µg/ft^2 is not directly comparable with the interim standard of 100 µg/ft^2 without some conversion factor to take into account the different methods.

- No sources of lead exposure other than carpet dust were considered when predicting blood-lead concentration.

Clark et al., 1995

This study investigated the correlation of dust-lead loadings between dust samples of various collection methods and from various surface types, as well as the correlation between dust-lead levels and children's blood-lead concentration. Sampling took place in 53 housing units containing children aged 6-72 months who were exposed to lead-based paint hazards and residues from lead mining smelters which ceased operations 30 years earlier. Within each housing unit, the following types and numbers of dust samples were collected:

- three side-by-side wipe dust samples, each on a 0.67 ft^2 uncarpeted floor area

- a single DVM dust sample on a 2.0 ft^2 uncarpeted floor area adjacent to the wipe samples (denoted "DVM-1 sample")

- a single DVM dust sample taken from three floor locations: the child's bedroom, the room most utilized by the child, and the interior entryway (denoted "DVM-2 sample"). This composite sample was generally obtained from a mixture of carpeted and uncarpeted floors.

The geometric mean dust-lead loading in the DVM-2 samples was higher (26 µg/ft^2) than for dust samples from exclusively uncarpeted floors (6 µg/ft^2 for the DVM-1 dust samples and 12 µg/ft^2 for the wipe dust samples).

A venous blood sample was also collected from the youngest resident child in each unit. The geometric mean blood-lead concentration across units was 5.3 µg/dL.

After taking logarithms of the collected data, the authors report a significant correlation of 0.28 (p=0.04) between blood-lead concentration and dust-lead loading in the DVM-2 samples (a mixture of carpeted and uncarpeted floors), and a significant correlation of 0.36 (p=0.007) between blood-lead concentration and wipe dust-lead loading. In contrast, the correlation between blood-lead concentration and dust-lead loading in the DVM-1 samples (exclusively uncarpeted floors) was not significant at the 0.05 level. The authors explain these findings by stating that the dust content in carpets is typically less variable from day-to-day than the dust content from uncarpeted floors, and therefore is more representative of a child's long-term exposure to lead in floor dust. In addition, children may spend more time on carpeted surfaces than uncarpeted surfaces. However, when adjusting for length of time that the child lived in the residence, age of child, socioeconomic status, and mouthing behavior within a regression analysis, the correlation between blood-lead concentration and dust-lead loading in the DVM-2 samples was no longer significant at the 0.05 level.

The authors note that the geometric mean dust-lead loadings in this study (6 µg/ft^2 to 26 µg/ft^2) were considerably lower than the interim HUD clearance standard of 100 µg/ft^2 for wipe dust samples, while more than five percent of the children in the study had blood-lead concentrations exceeding 10 µg/dL. If an objective is to have no more than five percent of children with blood-lead concentrations exceeding 10 µg/dL, this study suggests that lower dust-lead clearance levels are necessary (as was also concluded in Clark et al., 1996).

Hilts et al., 1995

In this study, performing repeated carpet vacuuming using a HEPA vacuum as a sole means of dust control was investigated relative to its effect on children's blood-lead concentration. The study took place in a lead/zinc smelting community in British Columbia. Fifty-five housing units received seven vacuumings over a ten-month period from 1992-1993, while 54 control units did not receive this cleaning. A HEPA vacuum with power agitator nozzle was used at a rate of 22-32 sec/m^2 to vacuum carpets, while non-carpeted areas were vacuumed at approximately 4 sec/m^2. Children in the treatment housing units ranged from 6 to 70 months of age and had initial blood-lead concentrations ranging from 4 to 26 µg/dL; children in control units had similar characteristics.

Prior to HEPA vacuuming, the DVM was used to collect composite dust samples from carpets in three areas of the unit where the child frequented. The Pearson correlation between blood-lead concentration and dust-lead loading was 0.50, which was significant at the 0.01 level; the correlation between blood-lead concentration and dust-lead concentration was 0.24, which was significant at the 0.05 level but not the 0.01 level.

In the group of 55 housing units where the repeated vacuuming took place, geometric mean blood-lead concentration declined from 11.9 µg/dL in the pre-vacuuming period to 11.0 µg/dL in the post-vacuuming period; testing this difference for statistical significance yielded a p-value of 0.06. However, the corresponding decline observed in the control units was 0.6 µg/dL, implying that the net decline in the treatment group was only 0.3 µg/dL, which was neither statistically nor clinically significant. Even when considering only specific groups of children (e.g., young children, children with high pre-intervention levels, etc.), net differences in blood-lead concentration were not statistically significant. Analyses indicated that a minimum decline in mean floor lead loading of 0.30 mg/m^2 (27.9 µg/ft^2) would be necessary to achieve a reduction in mean blood-lead concentration of 1.5 µg/dL. In this study, the mean difference in dust-lead loading between control and treatment units was only 0.16 mg/m^2 (14.9 µg/ft^2).

The authors point out that although the repeated HEPA vacuuming failed to result in significant declines in blood-lead concentration, no other lead-exposure reduction measures were taken in the units. The authors cite Mielke et al., 1992, as an example of how HEPA vacuuming and mopping with high phosphate detergent, in conjunction with other interventions such as soil cover, disseminating dust control information to residents, and cleaning painted surfaces, contributed to reducing blood-lead concentrations over a period where a seasonal increase in blood-lead concentrations was expected.

The Rochester Lead-in-Dust Study

Dust-lead loadings measured in the Rochester Lead-in-Dust study (Section 3.1) tended to be low. Pearson correlations between (log-transformed) dust-lead loading from carpeted floors and (log-transformed) blood-lead concentrations equaled 0.26 when wipe techniques were used, 0.27 when the DVM was used, and 0.36 when the BRM sampler (having a high flow rate) was used. These correlations were all significant at the 0.01 level. The correlations were lower when dust-lead concentrations were considered instead of loadings (0.18 for DVM method, significant at the 0.05 level, and 0.25 for BRM sampler, significant at the 0.01 level). These correlations increased from 10-40% (except for dust-lead concentrations under the DVM method) when adjusting for measurement error (Emond et al., 1997).

The correlations between blood-lead concentration and either dust-lead loadings or dust-lead concentrations tended to be lower for uncarpeted floors than for carpeted floors, especially with the DVM method. Lower correlations associated with the DVM sampler disagree with the statement made by Ewers et al., 1994, that high correlations exist between lead in surface dust collected by the DVM sampler and children's blood-lead concentrations.

The Rochester study concluded that lead-contaminated dust affects childrens' blood-lead levels, even when those levels are in the low to moderate range (< 25 µg/dL). This relationship differs according to the dust sampling method and the type of surface sampled. This study also concluded that dust-lead loadings were a better predictor of blood-lead concentration than dust-lead concentration, possibly the result of low dust-lead levels encountered in the study.

In the unpublished report by Hartford et al., 1996, pathways models were fit to data from the Rochester study to examine the routes by which lead infiltrates the residential environment and affects childhood blood-lead concentrations. The variables used in the pathways analysis of data from the Rochester study were as follows:

- Score representing a child's mouthing behavior (increasing value indicates increasing tendency to mouth window sill or put thumb, paint chips, or dirt in mouth)

- Average dust-lead loadings and dust-lead concentrations for each of the following: exterior dust (driveway and porch), interior non-entryway floors, interior entryway floor, window sills, window wells (BRM sample results only)

- Product of XRF paint measurements and paint quality ratings (1=poor, 2=average, 3=good), then averaged across window sills, wells, and sashes

- Product of XRF paint measurements and paint quality ratings (1=poor, 2=average, 3=good), then averaged across interior doors and jambs

- Indicator that the lead measurement in tap water exceeds 0.0005 mg/L

- Indicator of the presence of carpet in the interior entryway

- Proportion of the sampled areas which were carpeted

Note that the latter two variables indicate the extent of carpeting on sampled floors.

When considering either dust-lead loadings or dust-lead concentrations, the pathways models indicate that the presence of carpeting on the interior entryway had a significant direct association with blood-lead concentration (Hartford et al., 1996). The presence of carpeting on the interior entryway was associated with a significant decrease of approximately 30% in blood-lead concentration. This finding, along with floor dust-lead loadings being, on average, higher on carpeted surfaces than on uncarpeted surfaces and vice versa for concentrations, corroborated the usefulness of interior entryway mats for reducing soil tracked into the house. Increases in blood-lead concentration were associated with a decrease in the proportion of carpeted interior surfaces sampled. In addition, the direct pathway of the proportion of carpeted surfaces to blood-lead was not statistically significant. Results of these pathways analyses prompt the need for deeper investigations on the effect of carpeting on blood-lead concentration and on other environmental-lead measurements in housing with children.

Cambra et al., 1995

This study, conducted in the Greater Bilbao area of northern Spain, found no significant correlation between blood-lead concentration of 42 children aged 2 to 3 years and lead levels in house dust, when factors such as dust, water, and soil levels in areas where children frequent outside of the house are considered. The authors hypothesize that this result is due to high variability in lead levels within house dust and differences in the availability of house dust for ingestion by children, which were both a function of type of surface. The authors observed a high positive association between blood-lead concentration and lead levels in house dust from smooth floors, where dust was at higher lead concentration and was considered more readily available to children. However, they did not make the same conclusion between blood-lead concentration and lead in carpet dust. Lead concentrations in carpet dust had lower geometric means than from smooth floors.

While conclusions made in this study seem to be opposite those made in the study by Clark et al., 1995, this study focused on dust-lead concentrations, which other studies have concluded as having lower correlation with blood-lead concentrations than dust-lead loadings. This study also illustrates how adjusting for other factors can reduce the apparent effect of lead in carpet dust on blood-lead concentration, especially if lead levels in the carpet are lower than in other media.

Romieu et al., 1995

This study involved 200 households in two neighborhoods in Mexico City from 1992-1993. Each household contained a child under age five years, from which a blood sample was obtained via venipuncture (geometric mean = 9.9 µg/dL). Within the housing unit, dust samples were collected from carpets and furniture in the living room and bedrooms using the DVM, while uncarpeted floors and window sills were sampled using wipe methods. Generally, the housing units had low levels of lead in dust, soil, and paint. Average lead loading in 53 carpet dust samples was 5.6 $\mu g/ft^2$, which was lower than that observed for uncarpeted floors and window sill dust (sampled via wipe techniques), but similar to the 8.4 $\mu g/ft^2$ measured in 70 furniture dust samples (sampled via DVM).

Spearman correlation coefficients were calculated between lead measurements in the various environmental media (including carpet dust) and blood-lead concentration. These correlations were not significant at the 0.05 level. The correlation between carpet dust and amount of lead on hands was likewise not significant. However, in a separate regression analysis, the most significant predictors of blood-lead concentration were the use of lead-glazed ceramic to store or serve food, airborne lead (primarily from vehicular traffic), and lead in dust on children's hands. Therefore, it is likely that the unconventional lead sources observed in this study (lead-glazed ceramic, leaded gasoline emissions) dominated the effects that any other environmental factor may have had on blood-lead concentration. In fact, contrary to many studies that observe blood-lead concentrations peaking at approximately two years of age, this study observed a consistent increase in blood-lead concentration through age 50 months, partially due to the increased use of lead-glazed ceramics with age of child.

5.1.3 Carpet Lead-Dust Mitigation Issues and Approaches

Charney, 1982, was one of the first researchers to provide evidence that a regimented dust cleaning and control program in lead-contaminated houses can significantly reduce blood-lead concentrations in resident children. In his study involving 13 children 2-6 years of age with blood-lead concentrations exceeding 30 µg/dL, an average reduction of 6.1 µg/dL was observed when wet-mopping techniques were used on surfaces containing lead-contaminated dust on a biweekly basis for 20-27 weeks.

Section 5.1.3.1 presents the findings of studies that investigate procedures to mitigate lead-dust hazards in contaminated carpets. Results of investigations into factors which contribute to lead contamination of residential carpets, which are also considered when developing recommendations for preventing future contamination, are presented in Section 5.1.3.2

5.1.3.1 Mitigating Existing Lead Contamination

Most published investigations into lead-dust mitigation in residential carpets have only occurred in the past 15 years. An early recommendation for mitigating lead-dust in carpet was to perform wet vacuuming techniques (CDC, 1977). Recent studies to investigate the efficacy of various mitigation techniques have taken both laboratory and field testing approaches. The following published articles encountered in the literature search provide the most information on carpet lead-dust mitigation:

Milar et al., 1982
Ewers et al., 1994
Figley et al., 1992
Hilts et al., 1995
CSC and G&S, 1989
Steuteville, 1990

Most of these studies indicate that cleaning procedures performed improperly or with equipment incapable of proper cleaning can lead to no significant change, or even modest increases, in dust-lead loading or dust-lead concentration on carpet surfaces with which children can come in contact. This finding is especially apparent for carpets contaminated over time. Lead reduction over time is more likely when carpets are regularly cleaned with vacuums having agitator bars and when procedures are followed to prevent recontamination. Other studies have evaluated specific vacuum cleaning approaches. The findings presented within these articles are now presented.

Milar et al., 1982

The authors state that their work was prompted by a lack of any recognized published information on appropriate methods for removing lead-contaminated dust from carpets. Therefore, one objective of this study was to develop methods for mitigating housedust contaminated with lead. In this study, house dust in four housing units containing children with elevated blood-lead concentrations (at least 20 µg/dL) was sampled (using "vacuum assisted dry sampling") and analyzed for lead content. These units, which were among those considered in Dolcourt et al., 1978, contained no lead-based paint; rather, it was assumed that contamination resulted from lead being brought from the parents' workplaces. Average dust-lead concentrations in samples taken from carpeted and tiled floors ranged from 970 to 7171 µg/g in these units.

An initial attempt to mitigate dust-lead concentrations in carpets through conventional use of commercial carpet cleaning equipment (Steamex®) followed by wet-mopping with a sodium hexa-metaphosphate (Calgon®) solution (1 lb/5 gal water) failed to reduce the concentration. Therefore, an alternative carpet decontamination procedure was evaluated. In this procedure, the Calgon® solution was applied directly by the Steamex® carpet cleaner, then the carpet was recleaned 24 hours later with commercial cleaning solvents. If the carpet was not wall-to-wall, the underside of the carpet and the floor underneath the carpet were also cleaned. This alternative procedure resulted in a decrease in lead-concentration ranging from 30% to 50% and an average decrease in lead-loading of 60%. In one particular room, this procedure resulted in a decrease of 61% in lead-concentration and 91% in lead-loading, compared to 12% and 38% reductions, respectively, under a similar procedure which used exclusively commercial detergents throughout the procedure. The authors claim that the Calgon® solution reduces the electrostatic interaction between the carpet and lead-dust, allowing the detergents to remove the dust and the accompanying lead.

The authors indicate that repeated applications of the cleaning procedure was associated with declines in blood-lead levels in children within these units. However, this conclusion appears to be based on few children in a small number of units where lead in dust is the primary source of lead exposure. The authors also conclude that increased lead absorption in these secondarily-exposed children tends to occur when dust-lead concentrations from floors (including carpeted floors) exceed 1000 µg/g or 50 $\mu g/m^2$ (4.65 $\mu g/ft^2$).

Ewers et al., 1994

Dust-lead mitigation procedures used in the Cincinnati Soil-Lead Abatement Demonstration Project followed the approach investigated in Milar et al., 1982, with an additional step of dry-vacuuming with a HEPA vacuum. Through this experience and experiences in using repetitive dry-vacuuming procedures on carpets previously contaminated from abrasive paint removal procedures, led the authors to conclude that dust-lead loadings on the surface of carpets contaminated only once by lead-dust or soil may be successfully reduced by these cleaning methods. However, cleaning carpets that had received lead-dust over an extended period of time could actually increase lead-loadings within dust at the surface of the carpet and therefore most available to children. Therefore, the authors conducted a laboratory study to evaluate methods to mitigating lead-dust at the surface of heavily-contaminated carpets.

In the first phase of this study, nine samples of contaminated carpets obtained from inner-city units containing children with elevated blood-lead concentrations were brought to a laboratory. These carpets were cleaned with a HEPA vacuum with beater bar nozzle (at a long-pile setting) in ten cleaning efforts, each at a rate of one minute per square meter. The average percentage of total dust-lead loading removed in the iterative procedure increased from 42% to 74% from the first to the fourth effort. While lead concentration in the HEPA collection bags differed significantly across the carpets (at a 0.05 level), no significant differences across cleaning efforts were observed for a particular carpet. Thus, while the cleaning procedure performed equally well across all carpets regardless of their initial dust-lead concentration, no significant reduction in these concentrations was observed with the iterative cleaning procedure.

After specified cleanings of the contaminated carpets, the DVM was used to obtain dust samples for lead analysis. After the early cleaning efforts, surface dust-lead loadings actually increased in some carpets. However, average surface dust-lead loadings across the carpets decreased with the number of cleaning efforts (from 55% of the initial loading after the first effort, to 20% after the final effort), and all carpets had lower loadings after the tenth effort. Thus, some vacuum cleaning efforts may increase surface lead if not sufficiently repeated over time.

To evaluate variation in vacuum cleaning effectiveness, the second phase of the study considered new carpets (sculptured and short pile) contaminated with artificially-embedded dust within the laboratory. Three commercially-available HEPA vacuum cleaners (with beater bar nozzle at the long-pile setting) were used to clean the carpets. After one cleaning effort, the average lead loading for each vacuum was less than 25% of the embedded dust. While more dust was removed in early cleaning efforts from short pile carpets than from sculptured carpets, the overall cleaning efficiency from both types of carpets was relatively equivalent. The effects of vacuum cleaner type and the amounts and weights of dust added by the laboratory were significantly associated with the amount of dust recovered from the cleaning. The most efficient of the vacuums required six cleaning iterations before 70% of the embedded dust was collected.

The two phases of their laboratory study implied that repeated vacuuming was not sufficient in eliminating lead-dust from carpets, and occasional differences in cleaning efficacy between vacuum cleaners were observed. As a result, the authors concluded that it may be more practical to replace, rather than clean, a chronically-contaminated carpet.

<u>Figley et al., 1992</u>

The authors conducted a laboratory study in a controlled environment to evaluate various cleanup techniques for household dust contaminated by lead-based paint as a result of renovation activities. This study considered eight carpet cleanup techniques available to homeowners and general contractors. Using methods in ASTM, 1996b, new, medium-height nylon carpets were spiked with dust at either 1.0 or 40 g/m^2 (0.3% Pb); this dust was formulated to represent dust generated as a result of construction activities, rather than typical household dust. Carpets were cleaned using three vacuum types (new portable vacuum, new HEPA portable vacuum, used central vacuum) in conjunction with either plain cleaning tools or agitators, or by professional shampooing. The portable vacuums were tested with varying amounts of dust in the collection bag. The endpoint of interest was dust mass removal effectiveness (MRE):

$$\text{MRE} = \frac{(\text{sample mass after loading}) - (\text{sample mass after cleaning})}{(\text{sample mass after loading}) - (\text{sample mass before loading})} * 100\%$$

On carpeted surfaces, the MRE under the various techniques ranged from 18.5% to over 90%, a lower range than that observed in the study for vinyl flooring. Professional dry/wet cleaning failed to produce MRE values above those associated with residential vacuums with agitator tools. While HEPA vacuums produced moderate MREs regardless of whether plain cleaning tools or agitators were also used, MREs were low for portable residential vacuums with plain tools only. The study also found that the largest amount of dust removal occurred with the initial cleaning, with reduced amounts in subsequent cleanings. While the cumulative MRE approached 100% in vacuum techniques using agitator heads, the MRE could not reach 70% after at least 10 repetitions when only plain cleaning tools were used. The authors point out the need to retain precise control of humidity and laboratory procedures when conducting dust sampling tests on carpet.

This study also measured airborne lead levels within the laboratory chamber during cleaning techniques. Techniques using agitator bars were associated with lower airborne dust concentrations compared to those using plain cleaning tools. The highest airborne dust concentrations were observed when using a portable vacuum with an empty bag.

Hilts et al., 1995

This study, introduced in Section 5.1.2, investigated the efficiency of repeated HEPA vacuuming on floors as a dust control measure in 55 housing units. These units were cleaned with a HEPA vacuum (with power agitator nozzle) once every six weeks for ten months. Section 5.1.2 discussed how this dust control measure was associated with changes in blood-lead concentration of the resident children.

By taking DVM dust samples from carpeted floors prior to and after each vacuuming, this study observed an average 40% decline in carpet-dust loading and carpet dust-lead loading after each HEPA vacuuming, while carpet dust-lead concentration did not change significantly. The decline in carpet-dust loading was greater in units whose household vacuum did not include a power nozzle than in units whose vacuum did have a power nozzle, while the decline in carpet dust-lead loading was higher for units with vacuums having a low frequency of use compared to units that use the vacuum more often. Across the entire ten-month period, the geometric mean carpet-lead loading in treatment units decreased from 0.56 mg/m^2 at pre-intervention (52.0 µg/ft^2) to 0.36 mg/m^2 at post-intervention (33.4 µg/ft^2), which was significant at the 0.01 level. Significantly larger declines were observed for units not having a vacuum with a power nozzle, and for units in which residents vacuum less frequently. In contrast, no significant change in geometric mean carpet-lead loading was observed in 56 control units during this period.

Despite the significant decline in carpet-lead loadings over the ten-month period, the authors concluded that the cleaning intervention had no significant effect on children's blood-lead concentrations (as discussed in Section 5.1.2) and, in fact, was associated with a slight increase in hand-lead levels. The authors hypothesized that this result could have been partially due to residents' relaxing their own efforts in dust control as a result of the intervention. In fact, a small investigation in 18 of the 55 treatment units found that it took an average of 2-3 weeks following a HEPA vacuum cleaning before the unit would become recontaminated.

The study also included information from a 19-part self-reported survey which provided information on factors which can affect dust control in units. Resident use of a vacuum equipped with a power nozzle had significantly lower baseline carpet-lead and carpet-dust loadings. Units with dogs or cats had higher baseline carpet-lead loadings and blood-lead concentrations, implying more frequent dust tracking by pets. Also, units whose residents removed shoes at the door had significantly lower blood-lead and carpet-lead levels.

<u>CSC and G&S, 1989</u>

To evaluate the efficacy of the cleaning protocols involved in the Toronto pilot demonstration study (Section 3.1), samples of surface dust on floors were collected before, during, and after cleaning in each house, and were analyzed for lead content. These dust samples were collected from four high-traffic floor areas (primary entrance, rear/alternative entrance, in areas where children under six years frequent, and in some other obvious area of high traffic, with carpets having higher preference for sampling) using the DVM sampler and were analyzed using GFAA techniques. The sampling protocol called for the area to be beaten with a rubber mallet prior to sampling, to loosen the dirt and lead present.

Post-cleaning dust-lead loadings averaged 4 mg/m^2 (372 $\mu g/ft^2$) compared to 9 mg/m^2 (836 $\mu g/ft^2$) measured prior to cleaning. Despite this decrease, average dust-lead loadings in four of the eight houses were unchanged or marginally increased within one week after cleaning. Furthermore, at four months after cleaning, average dust-lead loadings in the eight houses increased to 5 mg/m^2 (465 $\mu g/ft^2$; although the dust sampling method was modified to involve a high vacuum pump).

Average dust-lead concentrations across the eight units increased from 1786 µg/g prior to cleaning, to 2016 µg/g immediately after cleaning, then declined to 1630 µg/g at four months after cleaning. The increase immediately after cleaning is likely the result of subsurface dust, with higher lead concentration, being brought to the surface as a result of cleaning but not removed by the cleaning. Significant declines in dust-lead concentration were observed in three of the eight houses after four months.

To measure the amount of lead that was removed by the cleaning process, dust and washwater collected by the cleaning equipment was sampled. The liquid samples were analyzed using USEPA Method 239.1 and 239.2. It was estimated that an average of 2 to 29 grams of lead were removed from each housing unit by the cleaning, which was considered a significant reduction of lead in the units. The majority of this lead was collected from dry vacuuming techniques. Approximately 42% of the total lead removed in dry dust came from floors (carpeted and uncarpeted), while 30% came from air ducts. Of all the wet cleaning techniques used on various surfaces, carpet shampooing removed the most lead.

The cleaning procedure did not appear to create a lead hazard to the cleaning workers. Results of 24 area air samples and personal air samples collected within the workers' breathing zones did not exceed 25.7 $\mu g/m^3$ over a day's shift.

The authors recommended from this demonstration that a special cleaning protocol be devised for carpets. Suggested protocols included cleaning both sides of carpeting using dry vacuums with agitator bars, completing the cleaning procedure with steam-cleaning methods, or removing the carpet and cleaning off-site when feasible. The authors also suggest that the lack of statistically significant differences in lead content between pre- and post-cleaning periods in this demonstration is partially due to the small numbers of units considered in the demonstration and the high variability in the sample results.

Steuteville, 1990

A pilot lead abatement/cleaning project took place in four housing units located in Throop, PA. The area was earlier contaminated by lead from the Marjol Battery Recycling Plant, resulting in extensive soil removal intervention activities. As part of a single thorough house cleaning conducted in November and December of 1989, the cleaning protocol (not detailed in the article) included vacuuming carpets. Dust samples were collected from carpets prior to and following the cleaning procedure using a "15 L/min air pump with a small orifice (and) filter attachment." As seen in Table 5-3, decreases in carpet-dust lead loadings were apparent immediately after cleaning. This decrease continued after two months of the cleaning for two of the four houses. However, one house saw an average increase after two months, and one house saw an average increase after 48 hours of cleaning. While measurement error must be considered when interpreting these findings, they also indicate that cleaning procedures must be performed properly, and lead in carpet-dust can return to high levels if some lead sources remain.

Table 5-3. Average Dust-Lead Loadings ($\mu g/ft^2$) in Carpeted Surfaces at Pre-Cleaning and Post-Cleaning in the Study Documented by Steuteville, 1990

Housing Unit ID	Dust-Lead Loading for Carpeted Surfaces ($\mu g/ft^2$)			
	Pre-Cleaning	48 hours Post-Cleaning	Difference	% Change
1	92.2	21.6	70.6	76.6
	32.3	7.4	24.9	77.1
2	51.3	29.9	21.4	41.7
	88.8	5.6	83.2	93.7
3	19.5	150.5	-131	-671.8
	36.2	8.7	27.5	76.0
4	4.6	2.0	2.6	56.5

Housing Unit ID	Dust-Lead Loading for Carpeted Surfaces (µg/ft^2)			
	Pre-Cleaning	48 hours Post-Cleaning	Difference	% Change
	32.0	6.7	25.3	79.1

5.1.3.2 Preventing Further Contamination

Studies have been published which investigated factors having a statistically significant effect on levels of lead in residential carpets. These studies conclude that preventive factors found to be significant, such as removing shoes prior to entry and placing walk-off mats at the entryways, should be taken into account when educating residents on ways to reduce the potential for contaminating carpets in the future.

Roberts et al., 1991a

These authors found the following variables as statistically significant predictors of dust-lead loadings in carpets: soil-lead concentrations, the practice of removing shoes prior to entry, use of walk-off mats at entrances, and use of vacuums with agitators.

In a study of environmental-lead levels conducted in 42 units in average or good condition, a regression analysis was performed to investigate those factors that were most statistically significantly associated with lead loadings in dust samples taken from carpets. The dust and soil samples were screened to include only particles smaller than 150 microns, as these particles were considered more likely to appear on a child's hand. An unrestricted stepwise regression analysis indicated that the optimal regression model on the log-transformed carpet dust-lead loading included the following effects:

- Log-transformed soil-lead concentration
- Indicator of whether shoes are removed at the door prior to entry (associated with an 8.9-fold reduction in carpet dust-lead loading)
- Indicator of whether a walk-off mat is present at the entry (6.4-fold reduction)
- Indicator of whether an agitator bar is found on the household vacuum cleaner (3.1-fold reduction).

The walk-off mat indicator variable was confounded with an indicator of whether wood-siding was present on the exterior. If the walk-off mat indicator variable is not considered in the stepwise regression, the optimal model includes the following effects:

- Log-transformed soil-lead concentration
- Indicator of whether shoes are removed at the door prior to entry (associated with a 12.8-fold reduction in carpet dust-lead loading)
- Wood-siding indicator variable (5.3-fold increase)
- Indicator of whether the carpet is wall-to-wall (4.3-fold reduction)
- Indicator of whether remodeling was performed in the last twelve months (3.3-fold increase)
- Housing unit age (1.03-fold increase per year)
- Indicator of whether indoor peeling paint was present (2.3-fold increase).

Variables not found to be statistically significant in either model include number of days since the carpet was last vacuumed, number of household members, presence of outdoor peeling paint, and an indicator of nearby automobile traffic density.

Note that both models include soil-lead concentration and whether or not shoes are removed at the entry. As a result, in three of these units, the authors did a small investigation of the benefits associated with removing shoes upon entry. In these units, geometric mean dust-lead loadings dropped from 17,100 to 250 $\mu g/m^2$ (1,589 to 23.2 $\mu g/ft^2$) after at least five months of removing shoes at the entryway. In one house that placed a walk-off mat at the entrances, it took more than one year to remove dust-lead in the carpet when using conventional vacuuming methods and approaches. Benefits of shoe removal were also observed in Hilts et al., 1995, where the difference in geometric mean blood-lead concentration between children in units where everyone removes shoes at the door (10.6 µg/dL) was significantly lower at the 0.05 level than other children (12.8 µg/dL). Throughout the Hilts study, households whose residents left shoes at the door prior to entry had lower floor dust-lead loadings and blood-lead concentrations than households whose residents wore shoes in the house. These findings conclude that a major source of lead dust in carpets is track-in from exterior sources.

5.2 FURNITURE

Section 4.2 provided an overall summary of the findings of the literature search and review on lead exposures associated with furniture, upholstery, and window treatments, and how to mitigate such exposures. As the number of articles and the extent to which information was presented in these articles were limited, this section presents further details on the relevant findings and conclusions within these articles on a study-by-study basis rather by research area. A brief indication of the research area(s) addressed by each encountered study is provided in

Table 5-4. The studies in this table, and in the presentations that follow, are sorted according to the primary research area addressed: lead measurement, association with blood-lead concentration, and mitigation.

Table 5-4. Research Areas Addressed in Studies Containing Information on Lead Exposures Associated with Dust in Furniture, Upholstery, and Window Treatments

Study/Reference	Research Areas Addressed[1]			
	Method Develop-ment	Characterizing Dust-Lead Levels	Association with Blood-Lead Conc.	Dust Cleaning/ Mitigation
Roberts et al., 1993	✓	✓		
Al Radady et al., 1994		✓		
Baltimore R&M study (USEPA, 1996b)		✓	✓	
Romieu et al., 1995		✓	✓	
CPSC, 1996 (press release)			✓	
Toronto pilot demonstration study (CSC and G&S, 1989)				✓
Steuteville, 1990		✓		✓
CH2M Hill, 1991 (via Ewers et al., 1994)				✓
Roberts, 1997				✓

Roberts et al, 1993

Section 5.1.1.1 summarized features of the HVS3 and a modification, the BRM sampler, as they pertained to sampling dust from carpets. Because of its design, the HVS3 may prove difficult to use when collecting dust from upholstered furniture and draperies. Because the fabric used for upholstery cushions or drapery is lighter than carpet, the HVS3 nozzle may seal when dust samples are taken from this fabric. In addition, the size distribution and composition of dust particles may be different on upholstered surfaces than on carpets and floors. Therefore, a laboratory study documented in Roberts et al., 1993, was conducted to evaluate a modification of the HVS3 for collecting dust from upholstered surfaces: the High Volume Furniture Sampler (HVFS). This study compared the performance of the HVFS with the BRM sampler, which was used to sample upholstered surfaces (among other surfaces) in the Baltimore R&M study (Section 5.1.1.1).

The HVFS has essentially the same features as the HVS3 and BRM sampler except the nozzle is notched, and a Royal Can Vac™ (similar to the BRM) is used to move air. The notched nozzle allows a continuous air flow, thereby preventing the nozzle from sealing when used on the lighter fabric found on upholstered furniture. The Can Vac™ also comes with a shoulder strap allowing easy access to furniture and upholstered items.

This study evaluated the dust collection efficiencies of the HVFS and the BRM sampler on two types of fabric frequently used as coverings for the foam cushions of a couch. The HVFS was evaluated under light and heavy dust loading conditions. The HVFS collection efficiencies on four velvet surfaces, under both loading conditions, ranged from 82.2% to 93.6%, while the efficiencies ranged from 87.4% to 92.0% for the four flat poly-cotton covered cushions. For the BRM sampler, the collection efficiencies on three velvet surfaces ranged from 70.8% to 75.6% and from 84.2% to 91.1% for three flat poly-cotton cushions. Thus, the HVFS had slightly higher dust collection efficiencies on these surfaces than the BRM sampler.

As part of the validation of the HVFS on upholstered furniture, ten used couches were obtained from a Salvation Army collection center in Seattle. One dust sample was collected from each couch using the HVFS. Lead concentrations in these samples ranged from 130 to 380 µg/g, with an average of 229 µg/g. Lead loadings in these samples ranged from 2.7 to 94.9 µg/ft^2, with an average of 27.8 µg/ft^2.

Al-Radady et al, 1994

This study, conducted in the north of England in the spring and summer of 1990 and introduced in Section 5.1.1.3, investigated how lead-contaminated dust deposits on surfaces in residential homes. Among the surfaces sampled for dust in certain units were hard-surfaced furniture (i.e., not fabric-covered) and net curtains.

A wiping technique was used to obtain dust samples from furniture and other "hard, immobile" surfaces (e.g., walls, ceilings, window sills). When taking ten dust samples taken from hard-backed furniture, the average dust-lead loading in a newer home was 6.0 µg/ft^2, with a standard error of the mean equal to 0.8 µg/ft^2, while results in an older home averaged 21.4 µg/ft^2, with a standard error of the mean equal to 4.2 µg/ft^2. These averages were higher than for dust samples taken from walls and ceilings, but lower than for window sills. In a third housing unit, the deposition of lead over time was investigated by taking ten dust samples from solid furniture surfaces (among other surfaces) monthly from April to July. Average dust-lead loadings on these surfaces were slightly higher in June and July than in April and May.

The lead content in dust on net curtains was studied in two housing units. Net curtains are typically present in a house to protect privacy and are generally always drawn. Prior to washing, three sets of net curtains were identified that had been in normal use and unwashed for a period of one year. Each set of curtains was placed into a large plastic bottle, in which a 10% (v/v) nitric acid solution was added and the bottle shaken and rotated for one hour. The leachate was then analyzed for lead content. When three iterations of this leaching procedure were performed, the total amount of lead removed on each set of curtains was 516, 535, and 797 µg, respectively. For each set, more than 90% of the recovered lead was removed after two iterations.

When measuring dust-lead loadings on net curtains, six sets of curtains were tested in a newer unit and seven sets in an older unit. The average dust-lead loading was 65.8 µg/ft^2, with a standard error of the mean equal to 13.6 µg/ft^2, in the newer unit, and 277.9 µg/ft^2, with a standard error of the mean equal to 16.5 µg/ft^2, in the older unit. When investigating the deposition of lead over time, average dust-lead loadings on curtains hung for a 28-day period in June or July tended to be higher (approximately 0.42 µg/ft^2) than for curtains hung for the same period in April or May (approximately 0.23 µg/ft^2).

USEPA, 1996b

Prior to any interventions being performed in the Baltimore R&M study (Section 3.1), dust samples were collected using the BRM sampler (Section 5.1.1.1) from upholstered furnishings in 60 of the 107 study units. Across the 60 pre-intervention upholstery dust samples, lead loadings ranged from 0 µg/ft^2 to 657 µg/ft^2, while lead concentrations ranged from 67 µg/g to 7879 µg/g. Table 5-5 contains the geometric mean dust-lead loadings and concentrations by unit classification, along with model-based 95% confidence intervals on these geometric means. The geometric means for modern urban units (assumed to be free of lead-based paint) were lower than the other unit classifications and were similar to geometric means for floors and window sills in these units. Among the other housing units, the geometric means were similar across unit classifications, but were considerably lower than the geometric means for the other surface types. Thus, in units with a potential for containing lead contamination (either resulting from previous abatement activities or the need for abatement), the geometric mean dust-lead loadings and concentrations for upholstery dust were lower than for floor-dust and for dust on window sills, window wells, and air ducts.

Table 5-5. Number of Dust Samples from Upholstered Furniture Taken Prior to Intervention in the R&M Study, Along With Geometric Mean Dust-Lead Levels and 95% Confidence Intervals, by Unit Classification

Unit Classification	# Dust Samples	Dust-Lead Loading (µg/ft^2)		Dust-Lead Concentration (µg/g)	
		Geometric Mean	95% Confidence Interval on Geometric Mean	Geometric Mean	95% Confidence Interval on Geometric Mean
R&M units (low level)	23	67	(35, 127)	699	(493, 992)
R&M units (mid level)	7	65	(11, 366)	700	(180, 2722)
R&M units (high level)	0	--	--	--	--
Previously-abated units	14	51	(25, 104)	503	(353, 718)
Modern urban units	16	10	(5, 20)	142	(101, 200)

Correlation coefficients were also calculated for dust-lead concentrations and dust-lead loadings between the various surface types sampled. For dust-lead concentrations, correlations between upholstery and other surfaces ranged from 0.41 for floors in rooms without windows (significant at the 0.05 level) to 0.68 for interior entryways (significant at the 0.01 level). The correlation between dust-lead concentration on upholstery and soil-lead concentration at the unit's dripline was 0.71, which was significant at the 0.01 level. For dust-lead loadings, the correlations with upholstery ranged from 0.34 for exterior entryways to 0.52 for window sills, with all correlations significant at the 0.01 level. Thus, dust-lead levels in upholstery appeared to be equally correlated with levels on other surfaces, and the correlation was significant.

The Baltimore R&M study also took venous blood samples from children residing in study units and investigated the correlation between blood-lead concentration and pre-intervention environmental-lead levels. Correlation coefficients calculated between the blood lead concentration of the youngest child in each household (N=73) and the log-transformed dust-lead loading and dust-lead concentrations for upholstered furnishings were 0.50 and 0.64, respectively. Both of these relationships were statistically significant at the 0.01 level and were the highest correlations with blood-lead concentration across all surface types sampled. When blood-lead concentrations for all children were considered (N=92), the correlations were 0.63 and 0.46, respectively, and remained significant at the 0.01 level. However, these correlation coefficients are not adjusted for effects of other lead exposure variables, such as floor dust-lead and soil-lead, on blood-lead concentration. Thus, the significant positive correlations with blood-lead concentration can only be interpreted as a significant association and not as a causal relationship. Further analysis of the R&M study data may determine whether a significant association exists between furniture or upholstery dust-lead after adjusting for the effects of lead in other household media.

Romieu et al., 1995

As introduced in Section 5.1.2, this study obtained environmental dust samples (including from furniture) and children's blood-lead concentration in 200 Mexico City households from 1992-1993. Furniture dust samples were obtained in the living room and bedrooms using the DVM; a total of 70 such samples had detectable lead amounts. These samples had an average dust-lead loading of 8.4 $\mu g/ft^2$, which was lower than that observed for uncarpeted floors and window sill dust (sampled via wipe techniques), but similar to the 5.6 $\mu g/ft^2$ measured in 53 carpet dust samples (sampled via DVM). The 200 children under five years of age on which a venipuncture blood sample was obtained had a geometric mean blood-lead concentration of 9.9 µg/dL. The Spearman correlation coefficient between lead loadings in furniture dust and blood-lead concentration was not significant at the 0.05 level, likely due to the low lead levels in furniture dust. When considering correlations among lead levels in different environmental media, lead levels in furniture dust was significantly correlated only with lead levels in floor dust on carpeted or uncarpeted floors.

CPSC, 1996

The CPSC has determined that certain foreign-made, non-glossy, vinyl miniblinds may present a lead hazard to young children. The miniblinds in question have lead as an ingredient to stabilize the plastic in the blinds. Tests run by CPSC determined that exposure to sunlight over time breaks down the plastic, thereby forming lead-contaminated dust on the surface of the blind. This dust can be a hazard to children if it becomes airborne or if children get the dust on their hands and put their hands in their mouth. The tests determined that the lead content in dust can vary from blind to blind. In some of the tests, CPSC found that "levels of lead in the dust was so high that a child ingesting dust from less than one square inch of a blind a day for 15 to 30 days could result in blood lead levels at or above the 10 µg/dL considered dangerous for young children." U.S. manufacturers have removed lead as an ingredient in miniblinds, and blinds without added lead became widely available in late summer 1996.

CSC and G&S, 1989

One objective of the Toronto pilot demonstration study of cleaning protocols (Section 3.1) was to investigate the percent of total lead removed from various surfaces using a cleaning procedure involving both wet and dry techniques. The cleaning procedure directed that dry HEPA vacuums without agitators be used to clean dust from three surface categories: floors, air ducts, and other surfaces (walls, shelving, upholstery, draperies, etc.). In addition, wet cleaning using tri-sodium phosphate-based cleaners, was performed on four surface categories: floors, carpets, upholstery, and walls. The amount of lead removed by both dry and wet cleaning methods was measured for each of the seven surface categories and expressed as a percentage of total lead removed by both stages of cleaning. On average across all eight housing units, only 1% of the total lead removed from this cleaning procedure was removed from upholstery using wet cleaning, while 16% was removed from the "other surfaces" category (which included upholstery and draperies) using dry HEPA vacuum cleaning. The percent of total lead removed from upholstery using wet techniques ranged from zero to three percent across the eight units, while the percent removed from "other surfaces" using dry techniques ranged from two to 37 percent.

Steuteville, 1990

One objective of this lead abatement/cleaning project in Throop, PA (introduced in Section 5.1.3.1), was to assess the effectiveness of removing lead from upholstered furniture. In three housing units, upholstery was cleaned using a regimen of dry vacuuming, followed by wet cleaning by some unspecified cleaning agent, followed by another dry vacuuming. Using a "15 L/min air pump with a small orifice (and) filter attachment," five pairs of dust samples from furniture were collected, where each pair consisted of a sample collected prior to the cleaning and a sample collected 48 hours following the cleaning. Table 5-6 lists the reported pre- and post-cleaning dust-lead loadings for each sample pair. The average change in dust-lead loading was a 5.5 $\mu g/ft^2$ decline with a standard error of 3.6 $\mu g/ft^2$, implying that the cleaning had no significant effect on the lead loadings measured from the upholstered furniture. However, four of the five sample pairs saw a decline in dust-lead loading from pre- to post-cleaning, with over a 40% decline observed in two of these pairs.

Table 5-6. Average Dust-Lead Loadings (µg/ft^2) for Upholstered Furniture at Pre-Cleaning and Post-Cleaning in the Study Documented by Steuteville, 1990

Housing Unit ID	Dust-Lead Loading for Upholstered Furniture (µg/ft^2)			
	Pre-Cleaning	Post-Cleaning	Difference	% Change
1	34.3	29.6	4.7	-16%
	32.5	19.0	13.5	-42%
2	26.6	13.7	12.9	-48%
	29.4	35.3	-5.9	+20%
3	19.9	17.8	2.1	-11%

CH2M Hill, 1991

A conclusion made within this article was briefly cited in Ewers et al., 1994. This study was a pilot study to evaluate the efficiency of HEPA vacuuming and shampooing of carpets and upholstered furniture from housing units located near a lead smelter in Bunker Hill, Idaho. While no specifics on the study design or methods were provided, the results indicated that an average of 18% of the total lead in furniture was removed following a vacuuming and three shampooings. This is in contrast to an average of 8% of lead removed from carpeting following an initial vacuuming, five shampooings, and a final vacuuming.

Roberts, 1997

This article presents a summary of published information on health risks associated with house dust, including lead exposure, and how a homeowner can reduce such risks. It includes the general statement, "Dust on rugs, furniture, curtains, clothes, and shelves contributes to the total exposure of everyone on the home, but especially to infants who crawl and mouth their hands." It is also cited that of the roughly 10 grams of lead in interior dust within a typical housing unit, approximately 20% comes from surfaces other than carpets and air ducts.

This article also outlines two ways to reduce the potential for lead hazard from dust on furniture, upholstery, and window treatments in the home. At least once a month, surfaces that can come into contact with residents should be vacuumed or washed. In addition, home owners should choose curtains and furniture that are easy to clean, as fleecy surfaces tend to act as reservoirs for dust and lead.

5.3 AIR DUCTS

Section 4.3 provided an overall summary of the findings of the literature search and review on lead exposures associated with air ducts, and how to mitigate such exposures. This summary was based on information from seven studies; the extent to which information was presented in reports and articles on these studies was generally limited. Therefore, this section presents details on the relevant findings and conclusions on dust contamination within air ducts on a study-by-study basis rather than by research area. A brief indication of the research area(s) addressed by each encountered study is provided in Table 5-7.

USEPA, 1995d; USEPA, 1996a

The Comprehensive Abatement Performance (CAP) Study, conducted in March, 1992, by Battelle and Midwest Research Institute for the U.S. EPA, measured lead levels in dust and soil in 52 privately-owned, single-family housing units in Denver, Colorado. These units participated in the HUD Abatement Demonstration Study approximately two years earlier (USEPA, 1996a). Thirty-five of these units had lead-based paint abatements performed in the HUD study, while the other 17 were found to contain no lead-based paint in the HUD study and were therefore not

Table 5-7. Research Areas Addressed in Studies Containing Information on Lead Exposures Associated with Dust in Air Ducts

Study/Reference	Research Areas Addressed[1]		
	Characterizing Air Duct Dust-Lead Levels	Association with Blood-Lead Conc.	Air Duct Dust Cleaning
CAP study (pilot study: USEPA, 1995d) (full study: USEPA, 1996a)	✓		
Toronto pilot demonstration (CSC and G&S, 1989)			✓
Lovelace et al., 1994	✓		✓
Cram et al., 1986	✓		
Baltimore R&M study (USEPA, 1996b)	✓	✓	
Angle et al., 1995	✓	✓	
R&R study (USEPA, 1997)	✓		

[1] No study characterized methods for collecting dust from air ducts, evaluated alternative dust collection methods, or investigated efforts to mitigate lead exposures associated with air ducts.

abated. The purposes of this study were to characterize lead levels in dust and soil in the selected units and to investigate how well the lead-based paint abatement methods succeeded in reducing these levels over time. Air ducts were among those surfaces from which dust samples were collected in the CAP study, as such dust was assumed to represent conditions prior to post-abatement cleaning in the units, and it was of interest to observe how lead levels in air ducts correlated with interior dust lead levels. As no blood samples were collected in the CAP study, this study characterizes lead levels in dust and soil, but does not relate such levels to an associated health effect in children.

In a 1991 pilot to the CAP study (USEPA, 1995d), dust and soil samples were collected from six Denver housing units. Using the Blue Nozzle vacuum method (Section 5.1.1.1), ten dust samples were collected from air ducts in five of these units, with from one to three dust samples collected in rooms in which lead-based paint abatement was performed in the HUD study (one air duct sampled per room). While the entire accessible surface of an air duct was to be sampled, each dust sample was taken from an average of 0.54 square feet of air duct surface. Dust-lead loadings in these samples ranged from 27 to 3,910 µg/ft^2, with a geometric mean of 308 µg/ft^2. Dust-lead concentrations ranged from 363 to 1,699 µg/g, with a geometric mean of 749 µg/g. These two geometric means were higher than those for all other surfaces except window wells. Using statistical modeling techniques, air ducts and window wells were the only surfaces for which both dust-lead loadings and concentrations were expected to be reduced following renovation and abatement activities.

In the full CAP study (USEPA, 1996a), the vacuum method used to collect dust samples from air ducts and other surfaces was changed to the CAPS cyclone to improve the sampling efficiency rate. Dust-lead loadings in 109 dust samples from air ducts ranged from 1.85 to 40,900 $\mu g/ft^2$, with a geometric mean of 120 $\mu g/ft^2$. Dust-lead concentrations ranged from 58.5 to 5,640 µg/g, with a geometric mean of 427 µg/g. These two geometric means were higher than those for floors and window sills, but considerably lower than those for window wells. The geometric mean dust-lead concentration was slightly higher, and the geometric mean dust-lead loading was slightly lower, than the corresponding geometric means for entryways (both interior and exterior). While dust loadings in air ducts could be extremely high, the geometric mean dust loading for air ducts (282 mg/ft^2) was from four to six times lower than that for window wells and entryways (both interior and exterior). Statistical modeling procedures estimated that within the units without lead-based paint (and therefore, no abatement), the geometric mean dust-lead loading in air ducts is 76 $\mu g/ft^2$, and the geometric mean dust-lead concentration in air ducts is 332 µg/g.

The full CAP study estimated that dust-lead loadings in air ducts were approximately four times higher, and dust-lead concentrations two times higher, in units predominantly abated using encapsulation/enclosure methods versus units predominantly abated using removal methods. These increases were significant at the 0.05 level. For other surface types, the differences in lead levels between these two groups of units were not significant at the 0.05 level. The increase associated with encapsulation/enclosure units when considering air ducts may be partially explained by the increased amount of abatement which these units tended to experience in the HUD study.

Also in the full CAP study, only in air ducts and soil were geometric mean lead loadings and lead concentrations significantly higher (at the 0.05 level) in abated units than in unabated units. For air ducts, geometric mean dust-lead loadings were approximately 4.7 times higher, and geometric mean dust-lead concentrations approximately 1.6 times higher, in abated units than in unabated units.

For air ducts in the CAP pilot study, the correlation between dust-lead loadings and dust-lead concentrations was 0.59, which was not significant at the 0.05 level. Dust-lead concentrations in air ducts were found to correlate highly with concentrations from bed/rug/upholstery, floors, window sills, and window wells as a group, after correcting for renovation and abatement effects. In the full CAP study, where tests for significant correlation had more power due to the larger sample sizes, the correlation in dust-lead loadings between air ducts and exterior entryways was significant (0.41).

The CAP study results indicate that air ducts can have among the highest dust-lead levels among interior surfaces, but they are generally lower than lead levels on window wells and, occasionally, on entryway floors. Dust-lead levels within air ducts tend to increase when performing activities which can disturb lead-based painted surfaces, as air ducts are typically not abated or cleaned upon conclusion of these activities.

<u>CSC and G&S, 1989</u>

One ingredient of the cleaning protocol used in the pilot demonstration project conducted by the City of Toronto, Department of Public Health (Section 3.1) was a cleaning of forced air heating ducts. In keeping with schedule limitations and to allow a quantitative measure of dust in air ducts, the air duct cleaning procedure involved "active surface contact throughout the duct by a portable-unit-powered suction head or nozzle, rather than the more commonly used technique of high-volume air flow drawn by a truck-mounted unit, assisted by limited mechanical agitation inside the duct." This process took from two to four hours per housing unit. The cleaning protocol required the following:

- No additional cleaning can proceed until 24 hours after completing the ductwork cleaning.

- Once the ductwork has been vacuumed, the air distribution fan was to be run for at least ten minutes, after covering each duct outlet by a cheese cloth or other filtration medium.

One objective of this demonstration study was to investigate the percent of total lead removed from various surface categories (e.g., floors, air ducts, upholstery) under the specified cleaning procedure. The amount of lead removed was measured for each surface category and expressed as a percentage of total lead removed from all categories by all stages of cleaning. On average across all eight housing units, 30% of the total lead removed by the cleaning procedure was removed from ductwork. This average percentage was second only to floors (42%). The individual housing unit percentages of the total lead removed that was collected from air ducts ranged from 7% to 65%, with three of the eight houses having a percentage exceeding 50%.

The study concluded that air duct cleaning did not appear to produce more airborne dust relative to other segments of the cleaning operation. Average airborne dust-lead concentrations were 0.285 $\mu g/m^3$ prior to cleaning, 0.764 $\mu g/m^3$ during ductwork cleaning, 0.612 $\mu g/m^3$ during the remainder of house cleaning, and 0.14 $\mu g/m^3$ at five to nine days following cleaning. The average during ductwork cleaning is only modestly higher than that during the remainder of house cleaning. Thus, in terms of limiting airborne lead concentrations, it may not be necessary to conduct air duct cleaning prior to any other cleaning in the unit. However, it is uncertain as to the extent of airborne lead dust measured during house cleaning that remains in the air following air duct cleaning.

While it was recognized that large amounts of total lead in the dust within a housing unit can exist in the air ducts, the study could not determine the extent to which this dust was assessable to residents of the unit.

Lovelace et al., 1994

While this case study took place in office buildings rather than housing units with children present, many of its findings are not relevant to this report. However, it provides some useful information on determining the magnitude of lead hazard associated with air ducts and the effect of general cleaning procedures on lead levels in air ducts.

An investigation of two North Carolina Department of Transportation office buildings by the North Carolina Department of Environment, Health, and Natural Resources uncovered lead dust present in these buildings. Air ducts in these buildings, shared by a common central steam station, were never cleaned since these buildings were built in 1953 and 1965, respectively. Considerable dust fallout was reported from the ductwork. As the HVAC system in these buildings were turned off at night, daily system start-up tended to dislodge dust.

In the summer of 1992, dust samples using wipe techniques (NIOSH Sampling and Analytical Method 7082) were taken from floors immediately outside of ductwork, as well as inside ductwork. Within ductwork, dust-lead loadings in 11 samples ranged from 71.0 to over 153,000 µg/ft^2. Outside of the ductwork, dust-lead loadings in 41 samples ranged from non-detectable readings to 614 µg/ft^2. Sources of lead in the dust included renovation activities and presence of exterior lead-based paint. Such findings prompted immediate cleaning of the ductwork and of surfaces throughout the building. No information was provided on the methods used to conduct this cleaning.

Upon conclusion of the ductwork and building cleaning, additional wipe samples were taken from inside and outside of the ductwork. Within ductwork, dust-lead loadings in six samples ranged from 145 to 18,000 µg/ft^2. Outside of the ductwork, dust-lead loadings in 13 samples ranged from non-detectable readings to 54 µg/ft^2. Thus, while maximum dust-lead loadings declined as a result of the ductwork cleaning, levels inside ductwork remained high, while areas outside of the ductwork had low levels.

Cram et al., 1986

This study also was conducted in an office building rather than a residence. Within each of the five stories of the air-conditioned building, built in an inner-city area of Great Britain in 1978, one dust sample was collected in each of two air ducts. The samples were collected by brushing the dust within a 1000 cm^2 area into a plastic sample bag.

In the first of two sampling rounds (December, 1985), dust-lead concentrations ranged from 1,428 µg/g to 6,550 µg/g, with a geometric mean of 2,667 µg/g. In the second sampling round (April, 1986), the range was from 1,084 µg/g to 5,344 µg/g, with a geometric mean of 1,856 µg/g. These concentrations were higher than that found on surfaces outside of the air ducts (800-1000 µg/g), but were similar to that found in outdoor street dust in the area. The authors hypothesize that low particle sizes associated with the outdoor dust allowed the dust to pass through ventilation filters and to deposit within the air ducts. In support of this hypothesis, the authors' claim that the dust particle sizes were similar to that of diesel smoke, which was attributed to causing a dark appearance to the dust collected in the air ducts. The study location had a proliferation of diesel traffic.

<u>USEPA, 1996b</u>

Prior to any interventions being performed in the Baltimore R&M study (Section 3.1), 29 dust samples were collected from horizontal portions of air ducts in primarily vacant units built prior to 1941 and awaiting repair and maintenance intervention (one of these samples was collected in a previously-abated unit). Dust samples were also collected from floors, window sills, window wells, and upholstered surfaces (upholstery was generally sampled when air ducts were not available). All dust samples were collected using the BRM cyclone sampler (Section 5.1.1.1).

Across the 29 pre-intervention dust samples from air ducts, lead loadings were extremely high, ranging from 2,829 µg/ft^2 to 942,329 µg/ft^2, while lead concentrations ranged from 79 µg/g to 11,248 µg/g. Table 5-8 contains the geometric mean dust-lead loadings and concentrations by unit classification, along with model-based 95% confidence intervals on these geometric means. In general, sample sizes were too low to make clear conclusions on lead levels among the different unit classifications. Among units not in the modern urban classification, geometric mean dust-lead concentrations for air ducts were higher than those for upholstery, similar to those for floors, and lower than those for window sills and window wells (USEPA, 1996b). While dust-lead loadings for air ducts were extremely high, they were similar in magnitude to dust-lead loadings in window wells. The high dust-lead loadings and moderate dust-lead concentrations associated with air ducts can partially be explained by the very high dust loadings found among air ducts relative to other surfaces in these units (older units awaiting interventions).

Correlation coefficients were also calculated for dust-lead concentrations and dust-lead loadings between the various surface types sampled. The correlation between dust-lead concentration in air ducts and dust-lead concentration on interior entryways (0.38) was significant at the 0.05 level, as was the correlation between dust-lead concentrations in air ducts and dust-lead concentrations in floors in rooms with windows (0.39). However, correlations in dust-lead concentration between air ducts and other surfaces (window sills, window wells, other floor areas) were not significant at the 0.05 level. While the correlation between dust-lead loading in air ducts and dust-lead loading on interior entryways (0.37) was also significant at the 0.05 level, no other correlation involving dust-lead loading in air ducts was significant for any other surface type. One reason for the low correlation and lack of significance was the low

Table 5-8. Number of Dust Samples from Air Ducts Taken Prior to Intervention in the R&M Study, Along With Geometric Mean Dust-Lead Levels and 95% Confidence Intervals, by Unit Classification

Unit Classification	# Dust Samples	Dust-Lead Loading (µg/ft^2)		Dust-Lead Concentration (µg/g)	
		Geometric Mean	95% Confidence Interval on Geometric Mean	Geometric Mean	95% Confidence Interval on Geometric Mean
R&M units (low level)	1	942,329	--	10,092	--
R&M units (mid level)	12	74,296	(31985, 172579)	1,445	(617, 3388)
R&M units (high level)	15	44,805	(23799, 84353)	1,491	(945, 2354)
Previously-abated units	1	22,045	--	466	--
Modern urban units	0	--	--	--	--

numbers of paired samples involving air ducts (N=39 in most cases) compared to the number associated with other surfaces.

The Baltimore R&M study also took venous blood samples from children residing in study units and investigated the correlation between blood-lead concentration and pre-intervention environmental-lead levels. Correlation coefficients calculated between the blood lead concentration of the youngest child in each household (N=11) and the log-transformed dust-lead loading and dust-lead concentrations for air ducts were not significant at the 0.05 level. The correlation was likewise not significant when blood-lead concentrations for all children were considered (N=15). However, these correlation coefficients were not adjusted for effects of other lead exposure variables, such as floor dust-lead and soil-lead, on blood-lead concentration. While further analysis of the R&M study data may determine whether a significant association exists between dust-lead in air ducts and blood-lead concentration after adjusting for the effects of lead in other household media, the low number of air duct samples would likely result in low power to detect significant associations.

<u>Angle et al., 1995</u>

Data from the Omaha Study of Childhood Lead were used, in part, to investigate the correlation between lead isotope ratios in the environment and ratios in the blood and urine of children in urban environments. This investigation addressed the issue of identifying the environmental source of lead exposure to these children, and in particular, the contribution of lead in food and in hand-dust to blood lead. Among the environmental samples collected in this study were air, soil, tap water, and dust from air ducts, floors in play areas, window sills, and door mats.

In this study, twenty-one children with mean age 2.2 years and balanced by gender, race, and socioeconomic status were included in this study. A total of 82 venous blood samples were collected over a 12-month period from these children; blood-lead concentrations in these samples averaged 6.4 µg/dL. Hand dust samples from these children were collected monthly during this period using wipe techniques.

A total of 21 dust samples from air ducts (one sample per surveyed housing unit) were collected using methods not reported in the paper. These samples had an average dust-lead concentration of 383 µg/g, with a standard deviation of 735 µg/g. No dust-lead loadings were reported for dust samples from air ducts. Lead levels in dust samples from other surfaces were expressed as dust-lead loadings, precluding a direct comparison with results from air ducts.

For all biologic and environmental samples, the isotopic ratio of ^{206}Pb to ^{207}Pb, labeled "IR", was measured. For air ducts, the mean value of IR across the 21 housing units was 1.1949, compared to 1.2027 for handdust. Using regression techniques, the annual mean IR for hand wipes ($PbBHW_{IR}$) was expressed as a linear function of the annual mean IR for air ducts ($PbDuct_{IR}$) in the following manner:

$$PbBHW_{IR} = 0.8057 + 0.3275*PbDuct_{IR}$$

This prediction was considered statistically significant at the 0.05 level. However, as adjustments for the effects of other environmental sources were not made in this analysis, it is uncertain as to the extent that this relationship is the result of high correlation with other exposure variables.

<u>USEPA, 1997</u>

In response to Section 402 © of the Toxic Substances Control Act, as amended within Title X, the USEPA conducted the Renovation and Remodeling (R&R) study. This study investigated the extent to which persons engaged in R&R activities in housing units containing lead-based paint are exposed to lead hazards during such activities or create a lead hazard as a result of the activities. The Environmental Field Sampling Study (EFSS) was a principal data collection effort within the R&R study, in which environmental measurements were taken in housing units containing lead-based paint, in order to assess the relative disturbance of and exposure to lead associated with selected R&R activities undertaken in these units. One phase of the EFSS, conducted in a controlled setting within a series of vacant, abandoned housing units, investigated lead disturbance and potential lead exposures associated with several R&R activities and generic activities that were difficult to isolate in an actual R&R job or were ingredients to larger R&R activities. One such activity was removal of HVAC ductwork.

In the EFSS, lead levels in dust within HVAC ductwork were determined in five housing units: two in Baltimore, Maryland, and three in Denver, Colorado. A total of 21 dust samples, collected using wipe techniques, were taken from the inside of the ductwork across these units (from three to five samples per unit). In units where ductwork removal was scheduled to occur as part of the study, the dust samples were collected prior to disturbing the ductwork. Table 5-9 presents descriptive summaries on lead loadings for dust samples from ductwork, across units and within each unit. The geometric mean of 2,900 μg/ft^2 was an order of magnitude higher than that observed in the CAP study (where occupied housing in previously-abated units or units free of lead-based paint were considered and air duct dust samples were taken using the CAPS cyclone vacuum method rather than wipe methods) but an order of magnitude lower than that observed in the Baltimore R&M study (where air duct dust samples were taken from housing awaiting repair and maintenance interventions using the BRM sampler).

Table 5-9. Descriptive Statistics on Dust-Lead Loadings for Samples Taken from HVAC Ductwork in the R&R Study, Calculated Across and Within Housing Units

Unit ID	N	Arithmetic Mean (μg/ft^2)	Geometric Mean (μg/ft^2)	Log Std. Dev.	Minimum Value (μg/ft^2)	Maximum Value (μg/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)
Source: USEPA, 1997.

The loading data summarized in Table 5-9 are plotted in Figure 5-1. This plot illustrates the variability in these data 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 approximately nine years prior to the dust sampling. These results indicate that settled dust found within interior HVAC ductwork can contain high levels of lead, to which residents can come into direct contact if the dust is disturbed. Indeed, lead disturbance resulting from HVAC removal (as measured by the amount of dust that settles in a fixed area surrounding the activity) was second to that resulting from demolition of structures containing lead-based paint, and was more substantial relative to other activities such as drilling, sawing, and sanding of structures containing lead-based paint, when standardizing the amount of each activity performed.

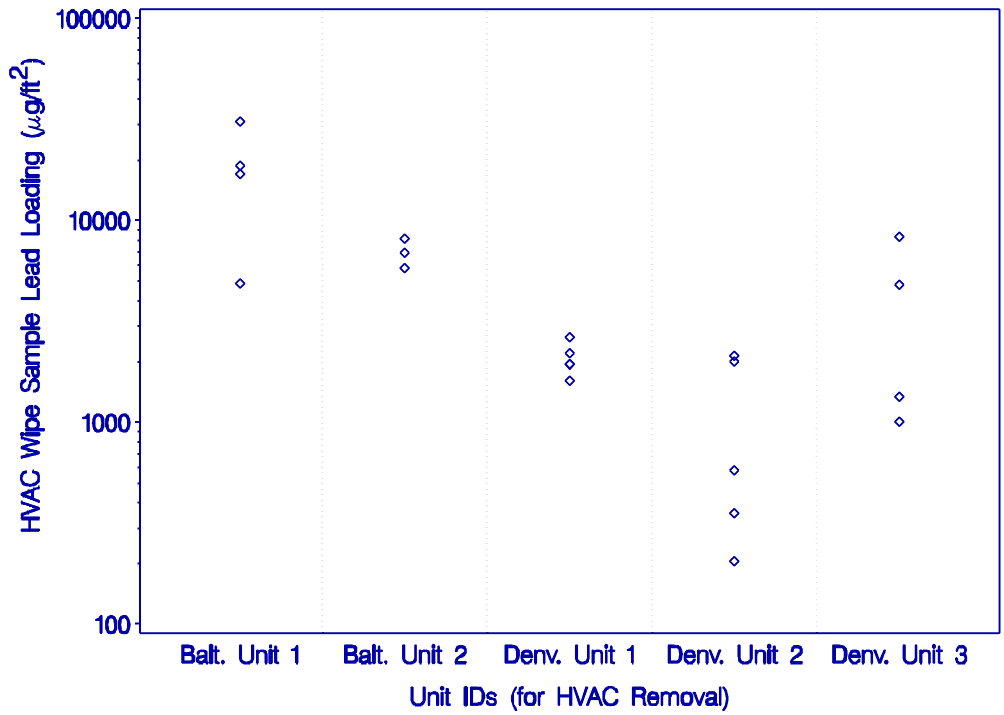

Figure 5-1. Lead Loadings (μg/ft²) Within Wipe Dust Samples Collected from Inside HVAC Ductwork in the R&R Study (Source: USEPA, 1997)

6.0 REFERENCES

This chapter lists the references cited in this report. Preceding each reference are codes indicating the topic area(s) that are addressed within the reference. These codes are as follows:

C = Carpet information
F = Furniture information
A = Air duct information

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