United States
Environmental Protection
Agency

Office of
Pollution Prevention and Toxics
Washington D.C., 20460

EPA 747-R-95-006
July, 1995

EPA

REVIEW OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS

July 24, 1995

EPA 747-R-95-006

FINAL REPORT

REVIEW OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS

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for

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This study was funded and managed by the U.S. Environmental Protection Agency. The review was conducted by Battelle Memorial Institute under contract to the Environmental Protection Agency. Each organization's responsibilities are listed below.

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Battelle was responsible for conducting the literature search, obtaining and reviewing the identified articles and reports, developing the conclusions and recommendations derived from the review, and preparing this report. In addition, Battelle developed and utilized a biokinetic model of the mobilization of bone-lead stores following an intervention.

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The Environmental Protection Agency was responsible for managing the review, providing guidance on the objectives for the review and report, contributing to the development of conclusions and recommendations, and coordinating the EPA and peer reviews of the draft report. In addition, EPA provided access to study results not yet available in the general literature. The EPA Work Assignment Managers were Bradley D. Schultz and Samuel Brown. The EPA Project Officers were Phil Robinson and Jill Hacker. Cindy Stroup, Barbara Leczynski, Dan Reinhart, Phil Robinson, and John Schwemberger reviewed the draft report and provided comments.

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EXECUTIVE SUMMARY

INTRODUCTION

This report is a comprehensive review of the scientific literature regarding the effectiveness of lead hazard intervention. One use of this review is to aid in assessing the potential benefits of Title X rule-making activities. In this report, a lead hazard intervention is defined as any non-medical activity that seeks to prevent a child from being exposed to the lead in his or her surrounding environment. An intervention, therefore, may range from the in-home education of parents regarding the dangers of a young child's hand-to-mouth activity to the abatement of lead-based paint. Interventions include activities that attempt to remove or isolate a source of lead exposure, as well as activities that attempt to reduce a child's lead exposure by modifying parental or child behavior patterns.

A number of studies have examined the effectiveness of abating the environment of lead hazards associated with lead-based paint, elevated dust lead, and elevated soil lead. These studies have emphasized hand-to-mouth activity as the primary pathway of childhood lead exposure and utilized interventions that targeted this pathway. Generally, they have assessed whether a particular intervention strategy effectively lowered an affected child's body-lead burden or the levels of lead in his or her environment. Sixteen such studies are summarized in this report. In total, these studies spanned 13 years, from 1981 to 1994. In all 16 cases, the interventions targeted primarily the child's residential environment. Also, the studied interventions principally sought "secondary" rather than "primary" prevention (e.g., assessing the effectiveness of lead hazard intervention on already exposed rather than unexposed children). Ten of the 16 studies focused on the abatement of lead-based paint as a primary form of intervention, five studies focused on dust or educational intervention, and one study focused on soil abatement.

It is often infeasible to directly assess health benefits following an intervention because many such benefits are subtle and, as such, are complicated and costly to measure directly. In this report, therefore, the blood-lead concentrations of exposed children are utilized as the primary measure of intervention efficacy. Blood-lead concentration can serve as a good surrogate health endpoint due to the established association between elevated blood-lead levels and adverse health effects.

MAJOR FINDINGS

The literature is very limited in its extent. However, it does indicate that blood-lead concentrations declined after lead hazard intervention, at least for children with blood-lead levels above 20 μg/dL.

The available literature only covers some of the intervention types and methods used in practice. However, declines on the order of 18-34% were measured in exposed children's blood-lead levels 6 to 12 months following a variety of intervention strategies. The evidence for blood-lead concentration declines after intervention among children with pre-intervention levels less than 20 μg/dL is mixed. With respect to changes in dust-lead levels, the declines following intervention were larger than the blood-lead level declines. However, dust levels are of limited relevance as a measure of actual exposure or health effects.

Four of the identified studies also simultaneously traced changes in blood-lead concentration among a population of children not receiving the studied intervention strategy. The effect of their interventions may then be estimated as the difference in the decline recorded for the study population and that for the "control" population. The four studies examined distinct intervention strategies: the abatement of damaged lead-based paint, the abatement of soil at elevated lead levels, regular dust control measures, and in-home educational outreach efforts. Using this measure, these four studies each would estimate the effect of their intervention to be approximately 15%. That is, those receiving the intervention were better off than those receiving partial or no interventions.

The evidence clearly indicates that short-term increases in exposed children's blood-lead concentrations may result when abatements are performed improperly.

Declines in blood-lead concentrations followed several removal methods, as well as some encapsulation and enclosure methods. In contrast, dry scraping and sanding with HEPA vacuum attachments were both reported to produce considerable elevations in the blood-lead levels of exposed children. Failure to clean-up post-abatement debris was also associated with residential dust and blood lead elevations.

There is simply insufficient information available to identify a particular intervention strategy as markedly more effective than others.

Evolution in the techniques associated with lead hazard control make comparison of the effectiveness of different practices difficult. The literature cites comparable reductions in blood-lead concentration resulting from the abatement of lead-based paint, dust at elevated lead levels, and soil at elevated lead levels. Moreover, declines in blood-lead levels after in-home educational efforts were observed in the same range as the other interventions, at least up to one year following intervention. As for long-term effectiveness, there is virtually no data on the effectiveness of any lead hazard intervention beyond one year following intervention.

Information is especially lacking on the effectiveness of interventions for children with blood-lead concentrations below 20 μg/dL. Also missing is data on effectiveness beyond one year after intervention and on the efficacy achieved by trying to prevent elevated blood-lead concentrations before they occur.

DISCUSSION

When considering the effectiveness of an intervention, it is important to recognize that childhood lead exposure stems from a number of media (e.g., paint, soil, interior house dust, exterior dust) across a range of environments (e.g., child's residence, school, playground, friend's residence). Unless an intervention targets all the sources of a child's lead exposure, therefore, even an intervention that fully abates the targeted source will not produce a 100% decline in the child's blood-lead concentration. If other sources of lead remain unaffected by the intervention, lead exposure may continue and the child's blood-lead concentration may remain elevated.

Another factor, bone-lead mobilization, can also cause blood-lead concentrations to remain elevated following interventions that reduce the targeted lead exposure. An intervention which reduces a child's lead exposure results in the mobilization of bone-lead stores into the blood. The available scientific information on bone lead mobilization is minimal, but a simple model of this mobilization was constructed in an effort to assess its impact. Bone lead mobilization modeling results in this report suggest that observed declines of as little as 25% in a child's blood-lead concentration might be possible for 6 months following an intervention which completely eliminates new lead exposure. The results also suggest that 25% declines in blood-lead concentrations which are observed at least 12 months after an intervention indicate the intervention was less than 100% effective in reducing the child's total lead exposure. However, mobilization of bone-lead stores is another reason why prevention of lead poisoning before it ever occurs is important.

Finally, in planning future studies of lead hazard intervention effectiveness, the timing of post-intervention measurements should be carefully considered. Environmental and blood lead measurements taken one year after intervention are usually appropriate because both seasonal variability and the effects of bone-lead mobilization are minimized. The timing of earlier measures should be based on such factors as the importance of observing transient elevations in blood-lead concentrations should they occur shortly after intervention, the importance of establishing a baseline for assessing recontamination of environmental media, and a trade-off between the effects of seasonal variability and bone-lead mobilization. Consideration should also be given to the population of children examined by future studies. There is a particular lack of information on the effectiveness of lead hazard intervention among children with blood-lead concentrations at or below 20 μg/dL Absent too is information on effectiveness at time periods beyond one year. Perhaps most importantly, information is lacking on the efficacy achieved by preventing elevated blood-lead concentrations before they occur. Fortunately, some on-going intervention studies are examining these populations, and should provide valuable information.

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1.0 INTRODUCTION TO THE PROBLEM

This report is a comprehensive review of the scientific literature regarding the effectiveness of lead hazard intervention. In addition, this review is intended to aid in assessing the potential benefits of Title X rule-making activities. In this report, a lead hazard intervention is defined as any non-medical activity that seeks to prevent a child from being exposed to the lead in his or her surrounding environment. An intervention, therefore, may range from the abatement of lead-based paint to the education of parents regarding the dangers of a young child's hand-to-mouth activity. Interventions include activities that attempt to remove or isolate a source of lead exposure, as well as activities that attempt to reduce a child's lead exposure by modifying parental or child behavior patterns.

In recent years substantial effort has focused on the development and demonstration of methods for reducing childhood lead exposure and body-lead burden by applying interventions which address environmental lead hazards. It is expected that these interventions will both prevent further exposure and produce positive health outcomes. The extent to which the scientific literature supports this expectation is characterized in this report. Currently available scientific information was compiled on the effectiveness of lead hazard intervention in reducing childhood lead exposure. These studies specifically address the efficacy of intervention strategies employed to reduce exposure to lead-based paint, elevated soil-lead levels, and elevated dust-lead levels. Moreover, these studies all sought to characterize interventions targeting already exposed children rather than unexposed children. As such, the studies measured "secondary" rather than "primary" prevention efforts. The literature currently reports no primary prevention studies, though some are being conducted.

Intervention has usually taken the form of abatements emphasizing the removal or enclosure of the source of lead exposure. Three recent studies identified methods involving either encapsulation, enclosure, or removal of lead-contaminated paint, dust, and soil. The Department of Housing and Urban Development (HUD), for example, conducted the Lead-Based Paint Abatement Demonstration Study to assess lead-based paint hazard abatement. The U.S. Environmental Protection Agency (EPA) subsequently conducted the Comprehensive Abatement Performance (CAP) Study to characterize the long-term efficacy of the paint abatement methods used in the HUD Demonstration, and the Three City Urban Soil Lead Abatement Demonstration (3-City) Project to investigate whether removal of leaded soil and dust from residential environments decreases the blood-lead concentration of children living in those residences.

Even if proven efficacious, applying the source isolation or removal methods cited in these three studies to our Nation's housing stock could prove to be prohibitively expensive. For this reason, a number of studies have been conducted, or are now under way, to examine the efficacy of low-cost abatement or in-place management intervention methods.

1.1 ORGANIZATION OF THE REPORT

Following in Section 2.0 is a discussion of the measures for assessing the efficacy of an intervention strategy. Two issues which impact the effectiveness of an intervention, bone-lead mobilization and source apportionment, are also considered. Section 3.0 is a review of the scientific evidence. Specifically, a number of studies are discussed that have examined the extent to which lead hazard intervention results in reduced lead exposure and lower blood-lead levels in children. While not exhaustive, these studies were found to contain the most pertinent information. Sections 4.0 and 5.0 present the conclusions and recommendations derived from the review. References, an Appendix A which contains abstracts of the studies, and an Appendix B containing a separate attachment regarding hazardous abatement methods, are included at the end of the report.

2.0 ASSESSING INTERVENTION EFFICACY

Assessing the effectiveness of a lead hazard intervention strategy is not always a simple undertaking. There are a wide range of parameters which may be measured to quantify the success or efficacy of an intervention. Section 2.1 presents several measures of effectiveness and outlines the parameters this report will rely upon in its review. There are also critical confounding factors which make the comparison of one intervention study to another challenging. Two such potential factors,

- source apportionment of lead exposure, and
- existing bone-lead stores,

are discussed in Sections 2.2 and 2.3, respectively.

2.1 MEASURES OF INTERVENTION EFFICACY

In reviewing a series of studies assessing intervention effectiveness, there are a variety of environmental, behavioral, and physiological parameters which may be measured to quantify efficacy. The goal is to utilize a measure which adequately reflects the potential benefit or detriment resulting from the intervention. Young children are the population most at risk from lead exposure and, as a result, are the target group for most of the intervention procedures commonly employed. A suitable measure of efficacy, therefore, should reflect the impact of the intervention on affected children. Interventions are not performed merely to reduce or eliminate environmental lead levels, the aim is always to positively impact the health of children or adults.

It would be ideal to precisely measure particular health outcomes, such as decreased learning deficits or increased motor coordination, among children benefitting from intervention. In fact, one study of moderately exposed children (detailed in section 3.1.13) did document increased cognitive function six months following a set of interventions. Unfortunately, identifying health outcomes following intervention is not always feasible. Such outcomes may not manifest themselves for a long period of time. Many of the health benefits are subtle and, as such, are complicated and costly to measure and verify. This assessment is made more difficult when considering interventions targeted at children with low to moderate lead exposure. Recognizing lead-related health outcomes is particularly difficult if the child was not exhibiting symptoms of lead poisoning before the intervention was initiated. In such instances, intervention efficacy may have to be assessed using tests of learning aptitude or intelligence quotient (IQ). The small differences recorded usually for these measures require larger sample sizes to statistically verify the benefit following intervention. For these reasons, it may be difficult and expensive to perform a sufficiently large study to demonstrate an intervention's effectiveness in this manner. As will be seen in the reviews in Section 3.0, the majority of identified studies did not measure specific health outcomes associated with their interventional practice.

Given these limitations, measures of body burden such as blood-lead concentration may serve as alternative biomarkers of lead exposure and intervention effectiveness. Such measures indicate the extent to which the intervention impacts affected children and serve as a biomarker of lead exposure. There is extensive evidence that body-lead burden is associated with lead levels in environmental media (USEPA, 1986; CDC, 1991). Three of the measures of body-lead burden reported in the literature are bone-lead content, blood-lead concentration, and erythrocyte protoporphyrin (EP) blood concentration. Bone-lead levels are considered to be reflective of cumulative exposure to lead, but their determination is currently either expensive or invasive. The accuracy and representativeness of bone-lead concentrations measured externally by an x-ray fluorescence (XRF) instrument is questioned by many researchers. Blood-lead and EP levels can be more readily measured, but often reflect a varying mixture of long-term and more recent exposure. There is an extensive body of literature relating blood-lead concentrations to specific health outcomes, though much of it examined children with higher levels of exposure (usually indicative of lead poisoning) (USEPA, 1986). Evidence, however, has been reported suggesting that even low levels of exposure, as measured via blood-lead levels, are associated with learning deficits (CDC, 1991; Goyer, 1993; Schwartz, 1994). The Centers for Disease Control (CDC) state that, "Data indicate significant adverse effects of lead exposure in children at blood-lead levels previously believed to be safe. Some adverse health effects have been documented at blood lead levels at least as low as 10 μg/dL" (CDC, 1991).[1] Reductions in blood-lead concentration, therefore, can be used as an effective measure of the results of intervention.

It is important to note that the effect of an intervention on blood-lead concentration is the change in concentration above and beyond that due to factors other than the strategy itself. The blood-lead concentration of a child may decrease due simply to random variation (regression to the

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Though the documented association between reduced blood-lead concentration and positive health outcomes is not based on interventional studies (with the exception of Ruff et al, 1993), it is strongly suggestive. Blood-lead concentration is associated with environmental lead exposure and linked to health outcomes. Moreover, temporal and sampling variability suggest the child's blood-lead levels have a 50% chance of increasing further. Intervention, therefore, eliminates the possibility that the exposure will be aggravated.

awareness of the health risk from lead. These decreases are usually characterized by examining a comparable control population. As a number of the identified studies did not examine a control population, we report the blood-lead concentration reductions of the studies population as the effectiveness of the strategy employed. When the results for control populations are available, we also report the estimated "effect" of the intervention.

When it is impractical or inappropriate to measure blood-lead concentrations, levels in environmental media can provide valuable information. Such measures cannot demonstrate the intervention's impact on affected children, nor has a quantitative relationship been established between environmental lead exposure and health outcomes. Environmental measures can, however, be used to evaluate the effectiveness of a particular procedure in reducing or eliminating a targeted lead hazard. In addition, there is extensive evidence that elevated lead levels in environmental media are associated with elevated blood-lead concentrations (USEPA, 1986; CDC, 1991). Environmental measures, however, do confirm the effectiveness of a particular procedure in reducing or eliminating a targeted lead hazard. Environmental measures may also be particularly appropriate for comparing different abatement procedures implemented on the same lead hazards and for assessing how successfully a particular source of the lead hazard is reduced. For example, dust-lead loading measurements on surfaces following their abatement can be used to demonstrate the superiority of one practice over another.

In the reviews and discussions that follow, any result which appears useful in assessing intervention efficacy will be reported. The primary measure used in this report, however, will be the blood-lead concentrations of exposed children. This measure of body-lead burden is commonly employed in assessing lead exposure and was collected in a majority of the identified studies.

2.2 IMPLICATIONS OF SOURCE APPORTIONMENT

When considering the effectiveness of an intervention strategy for reducing a child's body-lead burden, it is important to recognize the many different avenues by which a child may encounter lead. Intervention will be most efficacious if it targets those sources and pathways of lead exposure most responsible for the child's elevated lead burden. An intervention can reduce a child's lead exposure no more than that consistent with the source of exposure targeted. For example, if lead-based paint accounts for 50% of a child's lead uptake, even the complete abatement of that paint can be no more than 50% effective.

A child's daily lead exposure may occur across a number of micro-environments and lead hazards. Here, a micro-environment is defined as a location where a child spends a portion of their time. A lead hazard is defined as a potential source of lead exposure. Figure 2-1 presents an example of the micro-environments and lead hazards to which a child may be exposed. Note that the potential lead hazards can vary across micro-environments. The studies discussed in this report each involve the abatement or intervention of lead hazards at the primary residence of the child. The actual micro-environments and lead hazards that constitute a child's exposure depend upon a myriad of factors such as community, socio-economic status, age of child, and time of year. One child may play in leaded dust at his residence and leaded soil at school. A second child may obtain his or her exposure solely from lead-based paint contaminated dust at a friend's house. As a result, an abatement can reduce a child's lead exposure to a degree no greater than the degree to which the targeted source of exposure represents a hazard to the child. That is, if lead-based paint in the primary residence were responsible for 50% of a child's lead exposure, even a 100% effective abatement of the paint can only reduce the child's lead burden by 50%.

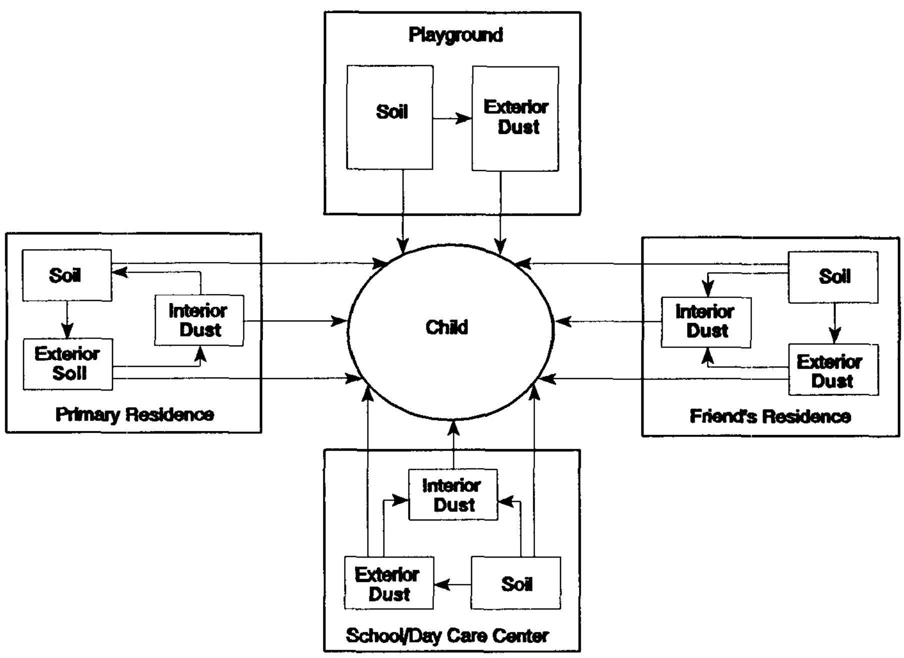

Figure 2-1. Micro-environments and lead hazards to which a child may potentially be exposed.

The efficacy of an intervention within a particular micro-environment is affected by the pathways of lead exposure targeted by the intervention. Each of the environmental lead hazards can be categorized as either an original source of lead or an environmental medium which acts as a reservoir for lead deposition. Major sources of lead in the environment include paint, industrial emissions, gasoline and solder. Lead from these sources can then accumulate in environmental media such as soil, dust, air, food and water. When an intervention strategy includes abatement of one of these environmental media, it is important to determine whether or not the media will become recontaminated from unabated sources. For example, abating elevated dust-lead levels within a residence will potentially result in only transient declines in the blood-lead levels of resident children. If the unabated source of lead (e.g., lead-based paint) recontaminates the dust, the child's blood-lead concentration may rapidly return to its original level. In a similar way, an intervention may target an existing reservoir of lead (e.g., lead-based paint), but not the intermediate media by which children are exposed to that reservoir (e.g., lead contaminated dust). Depending upon the rate at which the environmental media are recontaminated, the effectiveness of the intervention may be delayed.

Regulations on lead solder in cans and leaded gasoline emissions have greatly reduced the concentrations of lead in food and air. As a result, lead in paint, household dust and soil have been identified as the principal current sources of lead exposure for children (CDC, 1991). Potential interactions among these three sources and their associated pathways vary within a particular micro-environment. Figure 2-2 demonstrates some of the potential interactions and mechanisms by which children may be exposed.

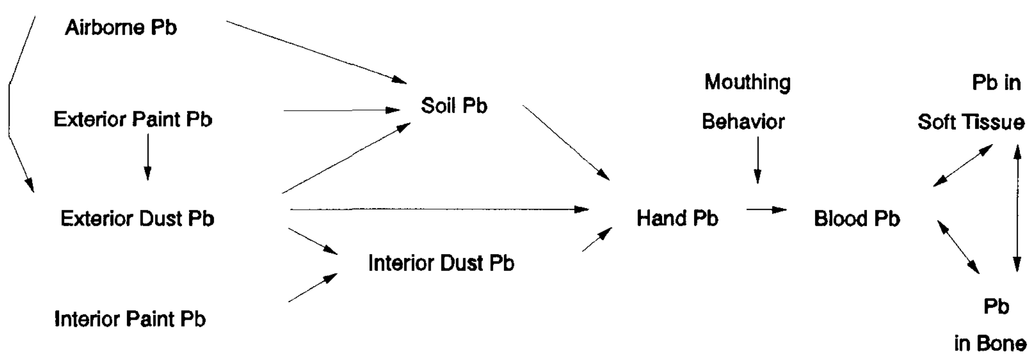

Figure 2-2. Pathway diagram detailing sources of lead exposure and their interactions within a particular micro-environment.

Each of the intervention strategies that are discussed in this report can be viewed as an attempt to reduce or eliminate one or more of the pathways that appear in the above diagram. Within a micro-environment, intervention should be targeted at those exposure pathways that have the greatest impact on the health of the child. The success of an intervention strategy is ultimately determined by the magnitude of the reduction in the body-lead burden of a child. Potentially, an intervention can be successful in reducing a particular environmental lead exposure and yet produce no positive impact in a child only marginally exposed to the abated lead hazard.

Though the sources of lead exposure responsible for a child's elevated body-lead burden often depend upon the individual, some attempts have been made to examine those issues for a "typical" child. One of the most commonly cited examples is presented in the EPA Air Quality Criteria for Lead (USEPA, 1986) which attributed typical human lead exposure to lead in food, water, dust, and inhaled air. Furthermore, a minimal or baseline level of lead was recognized for all children. This baseline body burden was, in turn, attributed to baseline levels of lead in numerous environmental media. A lead hazard, in this sense, would represent the amount of lead in a particular medium which greatly exceeded its baseline level. The EPA report (USEPA, 1986) estimated a typical child's daily lead exposure from a range of media. As this report was written in 1986, its estimates are now somewhat dated. To update them, a second EPA technical report (USEPA, 1989) was utilized. Three tables estimating typical exposures of a two-year-old child were developed from these two reports. Each table estimates the daily lead exposure from air, food, water, dust, and soil for a particular type of residence.

Table 2-1 describes the average daily lead intake for a two-year-old child who is exposed to only baseline lead levels. The occupational exposure represents the dust lead brought home from work by the child's parents. A child whose lead intake resembles this profile would probably not benefit from traditional interventions such as lead-based paint abatement. Note that the largest contribution to exposure is from elevated dust-lead levels. This is consistent with the many scientific literature citations of dust-lead as the primary pathway of exposure (CDC, 1991; Amitai et al., 1991; Roberts et al., 1991; Chisolm et al., 1985).

Table 2-1. Baseline Lead Intake for a Two-Year-Old Child

Environmental Media	Pb Concentration	Daily Amount Consumed	Daily Pb Intake	% of Total Intake
Inhale Air	0.10 μg/m^3	5 m^3	0.5 μg	2
Food, Water, Beverages	0.0033 μg/g	1500 g	5.0 μg	19
Dust - Household	300 μg/g	0.05 g	15 μg	57
Soil	90 μg/g	0.04 g	4.5 μg	17
Dust - Occupational	150 μg/g	0.01 g	1.5 μg	6
Total			26.5 μg	100

A child residing in an *urban* area will usually have greater lead intake (Table 2-2). Although the daily consumption rate remains unchanged for each of the environmental media in this table, the daily lead intake has increased due to higher concentrations of lead in household dust and soil in the urban environment. Even though the concentration of lead in air has increased from 0.10 to 0.75 μg/m^3, lead intake from inhaled air only accounts for about 3% of a child's total lead intake in the urban environment. Urban children whose lead exposure resembles the profile in Table 2-2 may benefit from intervention of exposure pathways associated with household dust and/or soil.

Table 2-2. Lead Intake for a Two-Year-Old Child in an Urban Environment

Environmental Media	Pb Concentration	Daily Amount Consumed	Daily Pb Intake	% of Total Intake
Inhale Air	***0.75 μg/m^3***	5 m^3	3.75 μg	3
Food, Water, Beverages	0.0033 μg/g	1500 g	5.0 μg	4
Dust - Household	***1000 μg/g***	0.05 g	50 μg	42
Soil	***1500 μg/g***	0.04 g	60 μg	50
Dust - Occupational	150 μg/g	0.01 g	1.5 μg	1
Total			120.75 μg	100

Table 2-3 shows the lead intake profile for children whose non-urban primary residence contains lead-based paint. Deterioration of this paint results in an average increase in dust-lead levels of 2200 μg/g over baseline values (from 300 μg/g to 2500 μg/g). In total, interior lead-based paint accounts for an additional 110 μg of lead in a child's daily lead intake through the paint-to-dust pathway. Abating leaded dust alone within a residence may induce only transient declines in the lead burden of resident children. If lead-based paint recontaminates the dust, then the lead burden of resident children may rise again shortly after dust abatement. In a similar fashion, if an intervention only targets the lead-based paint and ignores the resulting elevated dust-lead levels, there may be no body-lead burden reduction for quite some time. However, a thorough abatement of both lead-based paint and elevated dust-lead can theoretically reduce a child's lead intake by 80%, assuming that household dust-lead concentrations decline to 300 μg/g.

Table 2-3. Lead Intake for a Two-Year-Old Child in a Non-Urban House with Interior Lead-Based Paint

Environmental Media	Pb Concentration	Daily Amount Consumed	Daily Pb Intake	% of Total Intake
Inhale Air	0.10 $\mu g/m^3$	5 m^3	0.5 μg	0
Food, Water, Beverages	0.0033 μg/g	1500 g	5.0 μg	4
Dust - Household	***2500 μg/g***	0.05 g	125 μg	92
Soil	90 μg/g	0.04 g	4.5 μg	3
Dust - Occupational	150 μg/g	0.01 g	1.5 μg	1
Total			136.5 μg	100

These tables do not address a number of exposure scenarios potentially relevant to children including residential exterior lead-based paint or elevated soil-lead levels. Such scenarios could be developed but require additional assumptions and data. More importantly, Tables 2-1, 2-2, and 2-3 emphasize lead exposure exclusively from the child's primary micro-environment. Given the widespread presence of lead, it is entirely plausible that a child experiences lead exposure outside his or her home. Tables of total exposure could be developed for such scenarios, but they require assumptions about the child's exposure away from home. For example, one might assume a child spends 2/3 of his or her time at home and 1/3 away (e.g., at pre-school). Further, the pre-school could be assumed to expose the child to some fraction of the total exposure at home.

Thus, Tables 2-1 through 2-3 provide an oversimplified picture of lead exposure for children While consideration of such simplified models is useful in better understanding the lead exposure problem, most researchers readily recognize the more complicated nature of the problem and that non-residential micro-environments such as pre-schools and playgrounds also contribute to lead exposure.

2.3 INFLUENCE OF EXISTING BONE-LEAD STORES

When considering measures of body-lead burden it is important to recognize that lead is not stored in a single homogeneous pool within the body. Lead may be found in a number of organ systems including the blood, bone, kidney, liver, and other soft tissues, and is stored within each system at different concentrations. Therefore, a body-lead burden measure, such as blood-lead concentration, is a combination of recent and long-term lead exposure. This integration of exposures has implications for the assessment of intervention effectiveness. If the lead retained in the body from long-term exposure causes the blood-lead concentration to remain elevated, an otherwise successful intervention may appear to have had only marginal impact on the child's lead exposure.

Bone tissues exhibit a particular affinity for lead that results in the accumulation of lead concentrations in bone that are many times greater than the lead concentrations in other body tissues. Prolonged exposure to lead produces a considerable store of lead in the skeletal tissue (Barry and Mossman, 1970; Barry, 1975; Barry, 1981). Approximately 70% of a child's total body-lead burden is present in his or her skeleton, as compared to 95% in adults (Barry and Mossman, 1970; Barry, 1975; Schroeder and Tipton, 1968). For this reason, bone-lead content is often cited as an excellent measure of cumulative lead exposure. Furthermore, at least a portion of this lead is available for mobilization back into the blood (Barry, 1981; Rabinowitz et al., 1976).

The elimination of lead exposure sources in a child's environment should reduce the amount of lead absorbed into the child's blood from environmental sources, which should in turn reduce the child's blood-lead level. However, the resulting low blood-lead level is no longer in equilibrium with the lead concentrations in the bone tissues, resulting in the transfer of lead from the bone to the blood in an attempt to re-achieve an equilibrium. The lead which is mobilized from the bone to the blood in this fashion will maintain higher blood-lead levels than would be expected based on the reduced lead uptake from environmental sources. If blood-lead levels are maintained at significantly higher levels for periods of six months or more, the effectiveness of the lead hazard intervention could be seriously underestimated. This section examines the evidence for bone-lead mobilization within the scientific literature and employs a simple model of bone-lead mobilization to facilitate that examination.

2.3.1 Review of Evidence for Bone-Lead Mobilization

The kinetics of lead in bone have been predominantly examined in adults or in representative animal models. These results have then been extended to children, though this extension is a source of considerable debate. In many instances, bone tissue has been segmented into two categories: dense cortical bone and the more spongy trabecular bone (Leggett et al., 1982). Cortical bone is stated to have an average half-life for lead of 10-20 years, as compared to approximately 5 years for trabecular bone (Nordberg et al., 1991). This may be contrasted with an estimated one month half-life for lead in blood (Rabinowitz et al., 1976). Though bone is a significant storage site for lead, at least a portion of this mass of lead is available for mobilization back into the bloodstream. The percentage of the store available is unclear; some authors contend that bone may be further partitioned into pools of available and non-available lead (Rabinowitz, 1991). This turnover of lead is enhanced in periods of bone demineralization or reduced uptake of lead from environmental exposure (Nordberg et al., 1991). The latter conclusion was developed from studies examining adult bone and blood-lead levels following the elimination of occupational lead exposure (Hyrhorczuk et al., 1985). The body of research on bone tissue in children does suggest that "skeletal turnover is highest among children under 10 years of age [and] ... is strongly influenced by factors that include nutritional status, age and pathological conditions such as osteoporosis" (Nordberg, 1991). The measured concentration of lead in a child's blood, therefore, is a mixture of recent exposure and mobilized lead stores from bone and other organ systems that function as lead stores, but do not accumulate lead to the degree of bone.

Only one study was identified for which bone-lead levels were measured in children before and after an intervention; a study of the effectiveness of chelation therapy on low to moderately exposed children (mean blood-lead concentration, 32 μg/dL) measured bone-lead content by L-XRF pre-intervention and six weeks following enrollment (see Section 3.1.13 or (Rosen et al., 1991; Markowitz et al., 1993; Ruff et al., 1993)). Some researchers question the representativeness of L-XRF measures of mobilizable bone lead content. The interventions included residential lead-based paint abatement and $CaNa_2EDTA$ chelation therapy (administered within one week following enrollment) for children with positive lead mobilization tests (a procedure administered to assess whether chelation therapy may be appropriate). By six weeks post-enrollment, mean bone-lead content declined significantly (23%) among 71 chelated children, but did not for 103 children experiencing only lead-based paint abatement (3%). Results from a subset of these children report mean bone-lead content had declined 41% by six months following enrollment among an unreported number ($\leq$29) of chelated children, but had risen by 3% among 30 non-chelated children. The lack of decline among the 103 non-chelated children appears consistent with the marginal (9%) reduction in their blood-lead levels six weeks post-enrollment as compared with a mean blood-lead concentration reduction among the 71 chelated children of 19%.

This study suggests that bone-lead stores partially mobilize following reductions in blood-lead concentration due to lead hazard intervention. Other studies of chelation therapy effectiveness (Shannon et al., 1988; Graziano et al., 1988; Graziano et al., 1992) document a rebound in blood-lead levels following completion of treatment, presumably due to the enhanced mobilization of bone-lead stores. It remains unclear, however, the extent to which these existing stores may keep blood-lead concentration elevated following the intervention.

2.3.2 Modelling Bone-Lead Mobilization

Two parameters are necessary for assessing the extent to which bone-lead mobilization may mask the effectiveness of an intervention:

- the bone-lead mass (MBONE) to blood-lead mass (MBLOOD) ratio, MASSRAT (=MBONE/MBLOOD), and,
- the ratio of the rate at which lead is eliminated from the body to the blood-lead mass, KBLELIM, or normalized lead elimination rate.

In Section 2.3.2.1, data from the scientific literature is used to develop estimates of these parameters. In Section 2.3.2.2, these estimates are used in a two-compartment model of bone-lead mobilization to analyze the potential for masking effects.

2.3.2.1 Development of Parameter Values

In order to develop an estimate of the bone-lead mass to blood-lead mass ratio, autopsy data reported by Barry (1981) was utilized. Barry reported average lead concentrations in the blood, various bone tissues, kidney, liver, and other soft tissues of autopsied children in varying age groups. An overall bone-lead concentration was calculated as an arithmetic average of the lead concentrations reported for the rib, tibia and calvaria bone tissues.

A bone-lead concentration to blood-lead concentration ratio was then determined for each age group. A regression equation was fitted to the concentration ratio data to produce a predictive equation as a function of age. Values for the volume of blood and the mass of bone tissues in children (Altman and Dittmer, 1962; Harley and Kneip, 1984) of varying ages were then applied to produce a predictive equation for the bone-lead mass to blood-lead mass ratio (MASSRAT) as a function of age. Values of this ratio are presented in the second column of Table 2-4 for children 1 through 7 years of age. For example, the bone-lead store of an average 3-year-old child is estimated to be 20.66 times the mass of lead in the blood.

Table 2-4. Parameter Values Used in the Two Compartment Model of Bone-Lead Mobilization

Child's Age (years)	Bone-Lead Mass to Blood-Lead Mass Ratio [MASSRAT] (unitless)	Elimination Rate Constant [KBLELIM] (day^{-1})
1	14.72	0.068
2	17.33	0.062
3	20.66	0.059
4	24.05	0.056
5	27.42	0.054
6	30.75	0.052
7	34.04	0.050

Developing an estimate for the normalized lead elimination rate, KBLELIM, is more difficult; due in part to the complexity of the process of lead elimination from the body. KBLELIM can be interpreted as the fraction (unitless) of the lead in the blood that is eliminated from the body per day. Therefore, KBLELIM has units of $days^{-1}$. Lead exits the body via urine, endogenous fecal excretion of bile produced by the liver, and loss from other soft tissues such as hair, skin and nails. As a result, KBLELIM may be written as a function of the urinary lead elimination rate (URATE), endogenous fecal lead elimination rate (FRATE), and the rate of elimination via other soft tissues (ORATE):

$$KBLELIM = \frac{URATE + FRATE + ORATE}{MBLOOD}$$

$$= \frac{URATE}{MBLOOD} \cdot \left[1 + \frac{FRATE}{URATE} + \frac{ORATE}{URATE}\right]$$

Estimation of KBLELIM is based on the estimation of the following three ratios:

- ratio of urinary elimination rate to blood-lead mass (URATE/MBLOOD),
- ratio of endogenous fecal elimination rate to urinary elimination rate (FRATE/URATE), and
- ratio of elimination rate via soft tissues to urinary elimination rate (ORATE/URATE).

URATE/MBLOOD is estimated to be 0.022 $days^{-1}$ for adults based on eight adult studies (Rabinowitz et al., 1976; Campbell et al., 1981; Carton et al., 1981; Folashade and Crockford, 1991; He et al., 1988; Kawaii et al., 1983; Kehoe, 1961; Assenato et al., 1986). Each study contained data on the mean and standard deviation of an observed sample of measurements on blood-lead concentration and urinary-lead concentration (or urinary lead excretion rate). Whenever necessary, values of 50 dL and 19 mL/kg/day were substituted for the volume of blood and the daily volume of urine per kg body weight, respectively (Altman and Dittmer, 1962; Spector, 1956). FRATE/URATE is estimated to be 0.39 for adults based on two adult studies (Rabinowitz et al., 1976; Chamberlain et al., 1978). ORATE/URATE is estimated to be 0.17 for adults based on one adult study (Rabinowitz et al., 1976). Combining these three estimates using the above equation yields an KBLELIM estimate of 0.035 $days^{-1}$ for adults.

Since the estimate of KBLELIM was determined from adult data, it is necessary to extrapolate appropriate values for children. This is accomplished by scaling the adult estimates inversely proportional to body weight to the 1/3 power (Mordenti, 1986). That is,

$$KBLELIM_{child} = KBLELIM_{adult} \cdot \left(\frac{Body\ Weight_{adult}}{Body\ Weight_{child}}\right)^{1/3} .$$

Assuming an adult body weight of 70 kg, and using age-dependent mean body weights for children of various ages (Spector, 1956), the elimination rate constants in the third column Table 2-1 were derived.

2.3.2.2 A Simple Model for Bone-Lead Mobilization

In order to evaluate the potential for elevated blood-lead levels due to bone-lead mobilization, it is necessary to adopt a model for the transfer of lead between the blood and bone tissues within the body and for elimination of lead from the body. For this report, the simple model illustrated in Figure 2-3 was adopted. In this model, lead is taken into the body (from the gastrointestinal tract and lungs) via the blood, can transfer between the blood and bone tissue, and is eliminated from the body via the blood. Transfer of lead between the blood and bone tissues and elimination of lead from the blood are all assumed to follow a first-order kinetic relationship.

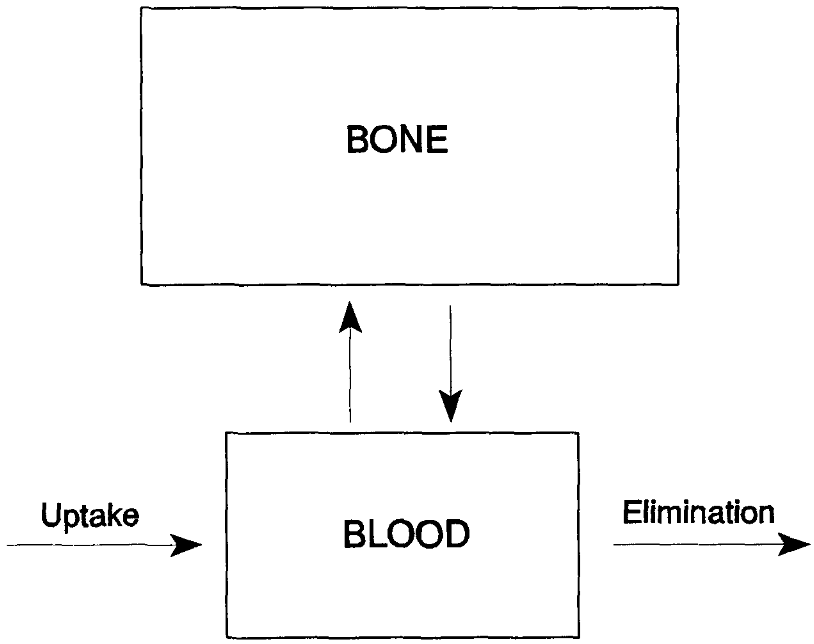

Figure 2-3. Two compartment model of bone-lead mobilization.

The adopted model is most certainly an oversimplification. However, the results produced using this model will approximate those of more complicated models involving additional tissue compartments for the following reasons:

- While lead does mobilize from non-bone tissues following a decrease in lead uptake, the effects are believed to be limited to a period of days or weeks due to the lower concentrations of lead amassed in these tissues, and
- While all lead elimination from the body does not occur via a direct pathway from the blood, the derivation of KBLELIM in the previous section properly includes these

other pathways (endogenous fecal and via other soft tissues) as if they were direct from the blood.

Using the model illustrated in Figure 2-3, blood-lead levels (PbB) after intervention would follow the relationship illustrated in Figure 2-4. There would be an initial drop in blood-lead concentration immediately after intervention to achieve a concentration that can be supported by the amount of lead being transferred from the bone. After this initial drop, blood-lead concentrations would follow an exponential decline toward the blood-lead concentration that can be supported by the post-intervention exposure level with no additional lead from the bone.

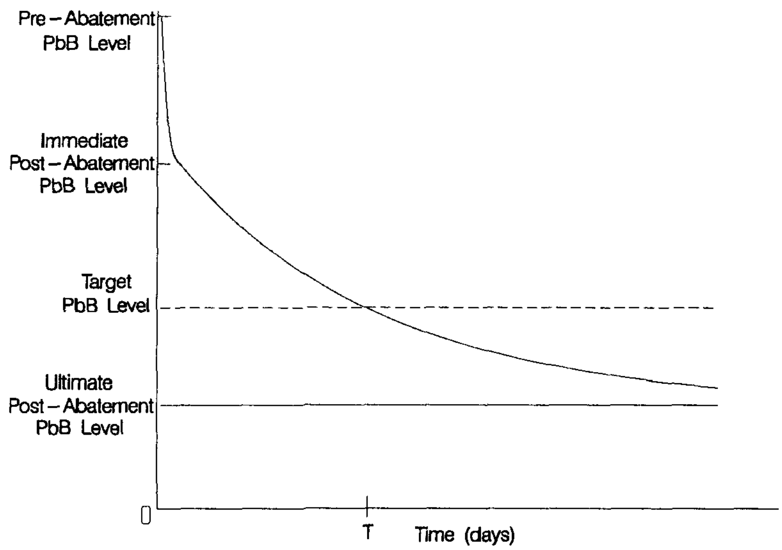

Figure 2-4. Blood-lead concentration versus time following a reduction in lead uptake

The emphasis in this analysis is the length of time a target blood-lead concentration can be maintained by lead mobilized from the bone. The length of time is illustrated by the symbol "T" on the horizontal axis in Figure 2-4. Specifically, the analysis considers a target blood-lead concentration (PbB_{Target}) which is 75% of the pre-intervention blood-lead level (PbB_{Pre}). This is because many of the studies to be discussed in Section 3.0 exhibit 25% reductions in blood-lead concentrations by 6-12 months post-intervention. When the target blood-lead level is 75% of the pre-intervention level, the maintenance time T is maximized by assuming that no initial drop in blood-lead level occurs immediately after intervention. That is, the maintenance time T is maximized by assuming that the lead mobilized from the bone is initially sufficient to maintain the pre-intervention blood-lead concentration.

Using this assumption, Figure 2-5 illustrates the expected decline in blood-lead concentration for a five-year-old child following three different intervention scenarios: 50% effective, 75% effective, and 100% effective. The blood-lead level is plotted as a percentage of the pre-intervention level. Note that the blood-lead concentration approaches 50% for the 50% effective intervention scenario, approaches 25% for the 75% effective scenario, and approaches 0% for the 100% effective scenario. The blood-lead concentration curves are governed by the following equation:

$$PbB = PbB_{LongTerm} + (PbB_{Pre} - PbB_{LongTerm}) \cdot \exp\left[-t \cdot \frac{KBLELIM}{MASSRAT}\right]$$

The time period for which the blood-lead level is maintained at or above the target level can, therefore, be calculated from the equation:

$$MaxTime = \ln\left[\frac{PbB_{Pre} - PbB_{LongTerm}}{PbB_{Target} - PbB_{LongTerm}}\right] \cdot \frac{MASSRAT}{KBLELIM}$$

Table 2-5 contains values of this time period for $PbB_{Target} = 0.75*PbB_{Pre}$ and $PbB_{LongTerm}$ equal to $0.50*PbB_{Pre}$, $0.25*PbB_{Pre}$, and zero for interventions which are 50%, 75%, and 100% effective, respectively. For these calculations, values of MASSRAT and KBLELIM were taken from Table 2-4. Note that the values of 11.8, 6.9, and 4.9 months for a five-year-old correspond to the time point at which the blood-lead concentration curves in Figure 2-5 cross the 75% line. For example, according to these model calculations, if an intervention reduces a five year old child's lead exposure by 75%, bone-lead mobilization can maintain blood-lead concentrations at or above 75% of their pre-interventional level for at most 6.9 months.

2.3.3 Conclusions Regarding Influence of Bone-Lead Stores

As will be seen in Section 3.0, the literature suggests six to 12 month post-intervention declines in blood-lead concentration of approximately 25%. Is it possible that the interventions were significantly more than 25% effective with bone-lead mobilization accounting for the elevated blood-lead levels? First consider blood-lead concentration measurements taken six months post-intervention. The last column of Table 2-5 would suggest that 100% effective interventions could maintain blood-lead levels at 75% of pre-intervention levels for six months for children ages 6-7 years. Interventions which are 75% effective could produce this result for children ages 4-7 years and interventions which are 50% effective could produce this result for children of any age. Thus, depending on the age of the child, interventions which are 50% effective or more could appear to be only 25% effective at six months post-intervention due to bone-lead mobilization.

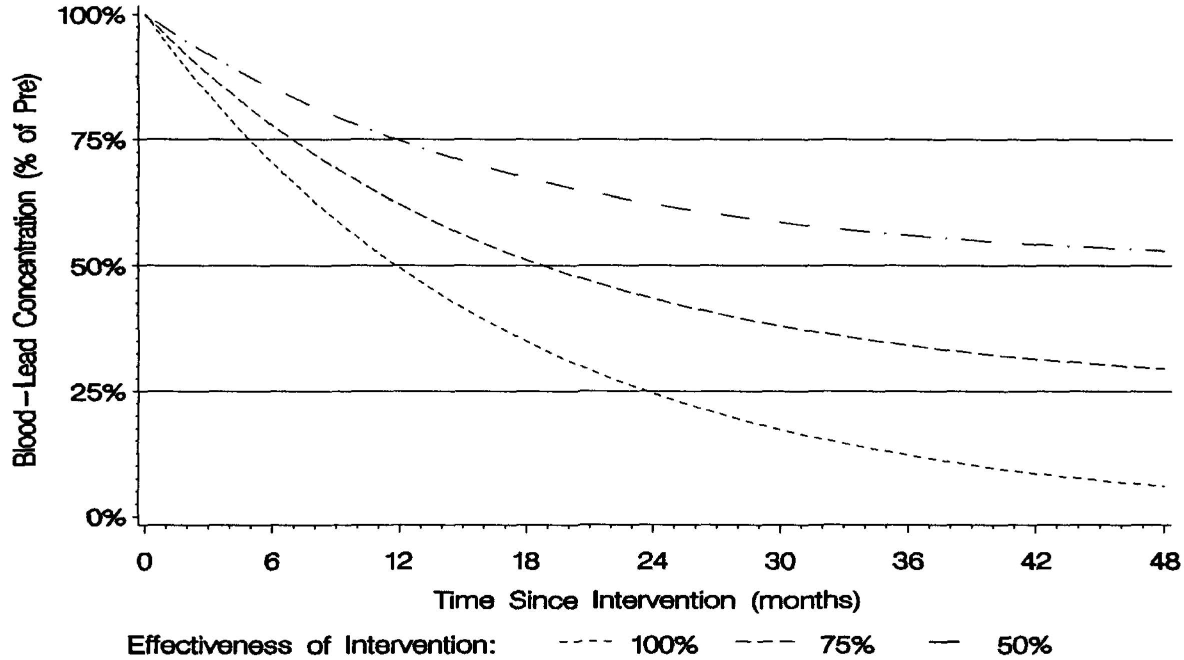

Figure 2-5. Blood-Lead Concentration Versus Time Following Interventions Which Are 50%, 75%, and 100% Effective.

Table 2-5. Length of Time (in Months) Bone-Lead Stores Can Maintain PbB at 75% of Pre-Intervention Levels

Child's Age (years)	Effectiveness of the Intervention		
	50%	75%	100%
1	3.6	2.1	1.5
2	5.0	2.9	2.1
3	6.7	3.9	2.8
4	8.6	5.0	3.6
5	10.5	6.2	4.4
6	12.6	7.3	5.2
7	14.7	8.6	6.1

Now consider blood-lead concentration measurements taken one year post-intervention. The last two columns of Table 2-2 would suggest that 75% effective and 100% effective interventions *cannot* maintain blood-lead levels at 75% of pre-intervention levels for one year for children of any age. Interventions which are 50% effective could produce this result, but only for children ages 5-7 years. Thus, for children ages 1-4 years, interventions which are 50% or more effective should not appear to be only 25% effective at one year post-intervention due to bone-lead mobilization. Further, interventions which are 75% or more effective should not appear to be only 25% effective at one year post-intervention for any age child.

After intervention of a particular source of lead exposure, the lead uptake experienced by an affected child should decrease. This decrease will produce declines in the child's body-lead burden as measured by the blood-lead concentration. However, as blood-lead levels decline, lead is simultaneously mobilized from existing bone stores. This masking effect can be considerable. Figure 2-6 presents the bias due to masking as a percentage of the target blood-lead concentration versus the time since the intervention. The modelling results generated for this report suggest that bone-lead stores, consistent with autopsy data, may be sufficient to singlehandedly maintain highly elevated blood-lead concentrations at six months post-intervention even when the interventions are highly effective. However, by one year post-intervention, the masking effect of bone-lead stores is diminished. Therefore, if blood-lead levels remain at 75% of pre-intervention levels for one year post-intervention, the intervention may have been significantly less than 100% effective.

These conclusions depend upon the cited experimental data and analytical assumptions used in developing the model of bone-lead mobilization. The estimated values of bone-lead to blood-lead mass ratio (MASSRAT) and the elimination rate (KBLELIM) are critical to the results presented in Table 2-5. The experimental data used to develop these estimates was culled from a thorough review of the available literature, but there is still only limited investigation in this area. The limited data implies that significant uncertainty is associated with the estimated parameter values and therefore, the maximum maintenance times. Similarly, the scaling factor used to extend the adult parameters to children has sound reasoning to support it, but there is little or no empirical data to validate its effect. These cautionary notes are not documented to question the viability of the reported analysis; the model's construction and the accompanying analytical procedures are valid. Rather, as additional research in this area is reported, its implications to the results in this section should be considered.

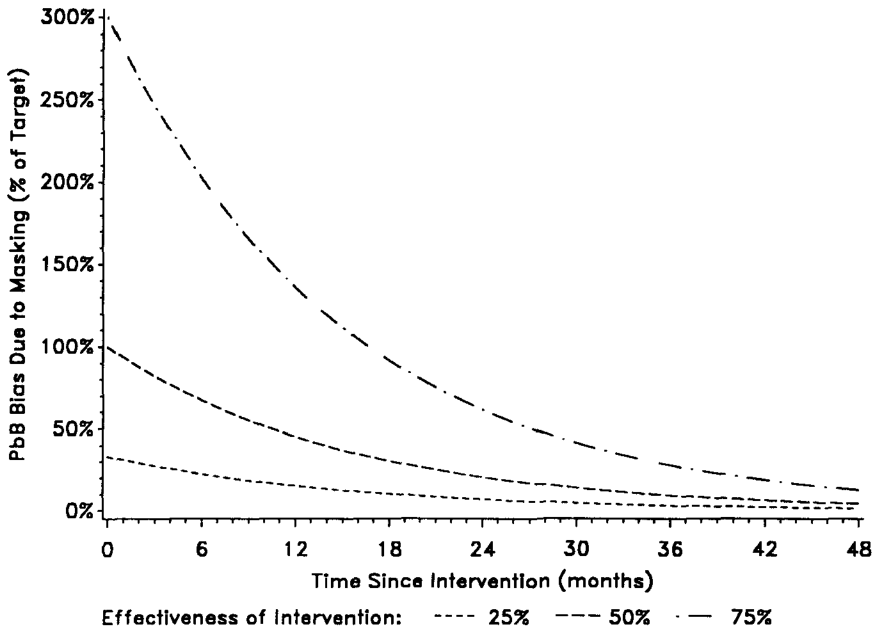

Figure 2-6. **Percentage bias in blood-lead concentration due to masking versus time following interventions which are 25%, 50%, and 75% effective.**

That interventions may be significantly less than 100% effective is quite plausible, since it is extremely difficult to identify and successfully isolate all the potential sources of a child's exposure. A study of 184 children (pre-intervention blood-lead concentrations exceeding 50 μg/dL), who were released following chelation therapy to "lead-free" residences, portrays the difficulty of reducing a child's lead exposure to zero (Chisolm et al., 1985). Mean blood-lead concentrations increased during the first three months following treatment and remained stable at these elevated levels thereafter. The mean blood-lead concentrations were significantly different across types of housing, with a greater mean blood-lead concentration observed for children living in or regularly visiting lead-based paint abated residences than for children living in "lead-free" public housing or "totally gutted and renovated old housing." The authors' suggested that blood-lead concentrations failed to decline because the children were still exposed to lead hazards, as the abated residences could be categorized into "adequately abated" and "inadequately abated." "It is quite possible that potentially hazardous sources of lead in the old homes were not always identified. (Chisolm et al., 1985)"

3.0 REVIEW OF SCIENTIFIC EVIDENCE

A variety of approaches were employed in an attempt to identify studies addressing the effectiveness of lead hazard intervention. These included the authors' knowledge of the available literature, two focused literature searches, an examination of the referenced articles cited in identified studies, and additional material provided by Bradley Schultz of the EPA. One literature search used keywords to identify journal articles or reports of potential relevance. The primary keywords were "lead" and "Pb." The secondary keywords were "intervention," "abatement," and "delead." An article or report was selected if its title contained one of the primary keywords and one of the secondary keywords. This search produced a list of 371 potential articles and reports. The second search was focused on non-domestic studies of lead hazard intervention. An examination of articles or reports written outside the United States and containing the keywords "lead" or "Pb" in the title produced a list of 721 documents. The two lists were reviewed and relevant articles (in addition to those already identified) were selected and acquired. These materials formed the literature base examined for this review.

A number of studies have examined the effectiveness of abating the environment of lead hazards associated with lead-based paint, elevated dust-lead, and elevated soil-lead. These studies regard hand to mouth activity as the primary pathway of childhood lead exposure. Generally, they assessed whether a particular abatement practice effectively lowered an affected child's blood-lead level or the levels of lead in his or her environment. In all cases, the studied interventions sought "secondary" rather than "primary" prevention (e.g., assessing the effectiveness of lead hazard intervention on already exposed rather than unexposed children). The intervention strategy considered also sometimes depended upon the assumed mechanism by which the child's environment becomes contaminated. One practice attempted to halt the soil track-in mechanism, while another continually reduced the elevated dust-lead levels within the home.

Sixteen such studies are summarized in this section. In total, these studies spanned almost 13 years, from 1981 to 1994. A timeline graph locating the period during which the interventions examined in each study were conducted is presented in Figure 3-1.

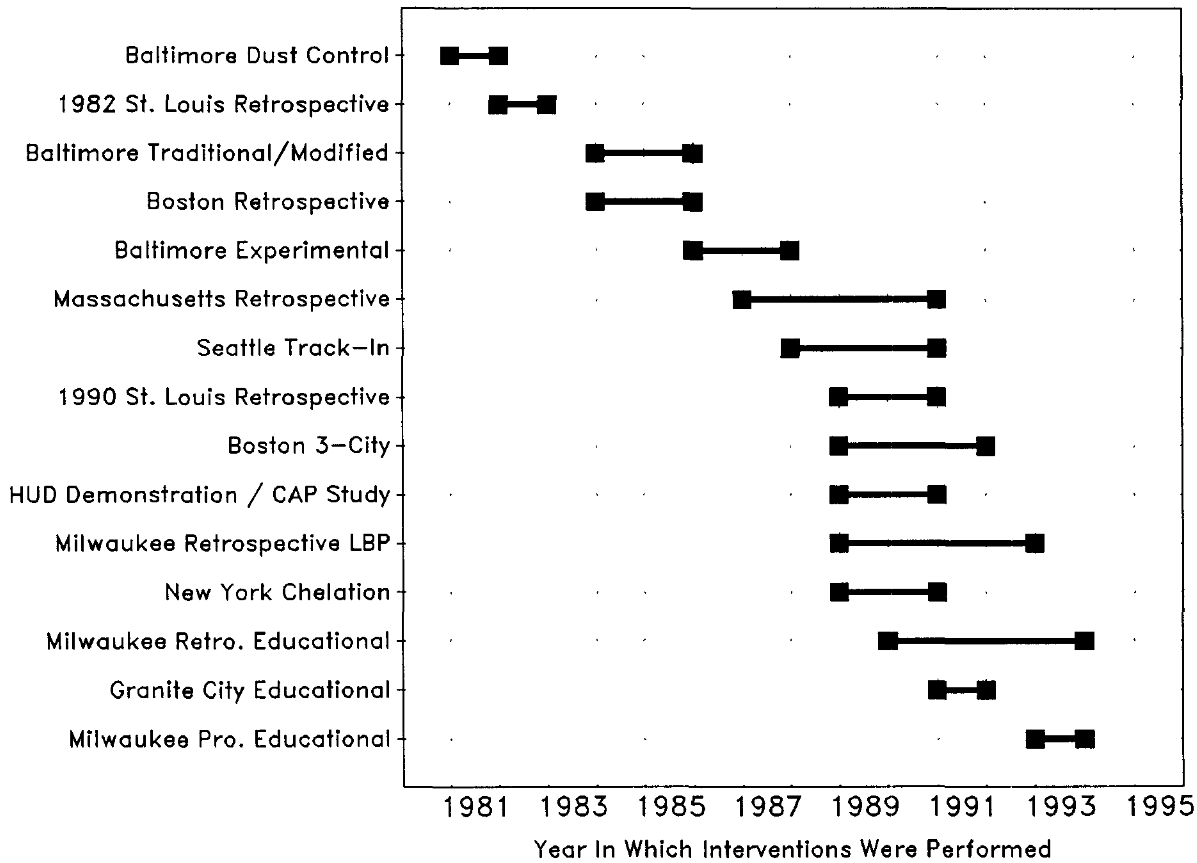

Figure 3-1. Timeline for the identified intervention studies.

Ten of the 16 studies focused on the abatement of lead-based paint as a primary form of intervention, five studies focused on dust abatement, and one study focused on soil abatement.

A detailed discussion of each of the 16 studies follows in chronological order. These studies are presented chronologically to emphasize the evolutionary nature of some abatement practices. The discussion includes the pertinent study objectives, the sampled population, the intervention approach studied, the environmental and body burden measures collected, the study design and results, and the conclusions relative to the efficacy of the intervention performed. Additional details are included in the study abstracts in Appendix A.

3.1. LEAD HAZARD INTERVENTION STUDIES

3.1.1. Baltimore Dust Control Study

This 1981 study (Charney et al., 1983) sought to assess whether periodic dust-control measures in addition to lead-based paint abatement would be more effective in reducing blood-lead concentrations than lead-based paint abatement alone. Forty-nine children aged 15 to 72 months with at least two confirmed blood-lead concentrations between 30 and 49 μg/dL formed the study population. Their residences had all undergone lead-based paint abatement entailing the removal of all peeling, lead-containing interior and exterior paint from the residence, and the removal of all lead-containing paint from chewable surfaces below 4 feet. No extensive clean-up procedures were required following the abatement. In addition to the abatement, the homes of 14 children in the experimental group received periodic dust-control measures involving two monthly visits by a dust-control team which wet-mopped all rooms in the residence where the dust-lead loading was identified in an initial survey as exceeding 100 μg/sq ft.

Venous blood samples were collected during regular visits to the clinic, approximately every 3 months during the course of the study. After 6 months, there was a significant reduction of 5.3 μg/dL in mean blood-lead concentration among the 14 children in the experimental group (wet-mopping and abatement) and a further decrease of 1.6 μg/dL after 1 year (Figure 3-2). In contrast, the mean value for the abatement only group did not change significantly over the 12 months. Residential dust-lead loadings were collected for the experimental group during recruitment. To assess the success in cleaning, dust-lead loading measurements were also obtained from all areas within the residence where the child spent a significant amount of time. These measurements were taken both before and after the dust-control teams completed their work. The samples were collected with alcohol-treated wipes within a 1 ft^2 area of floor or from the entire window sill. Within experimental residences, the bimonthly dust-control efforts reduced the dust-lead loading on measured surfaces (Figure 3-3). Dust measures were not collected in the abatement only group in order to avoid drawing attention to dust as a potential source of lead exposure.

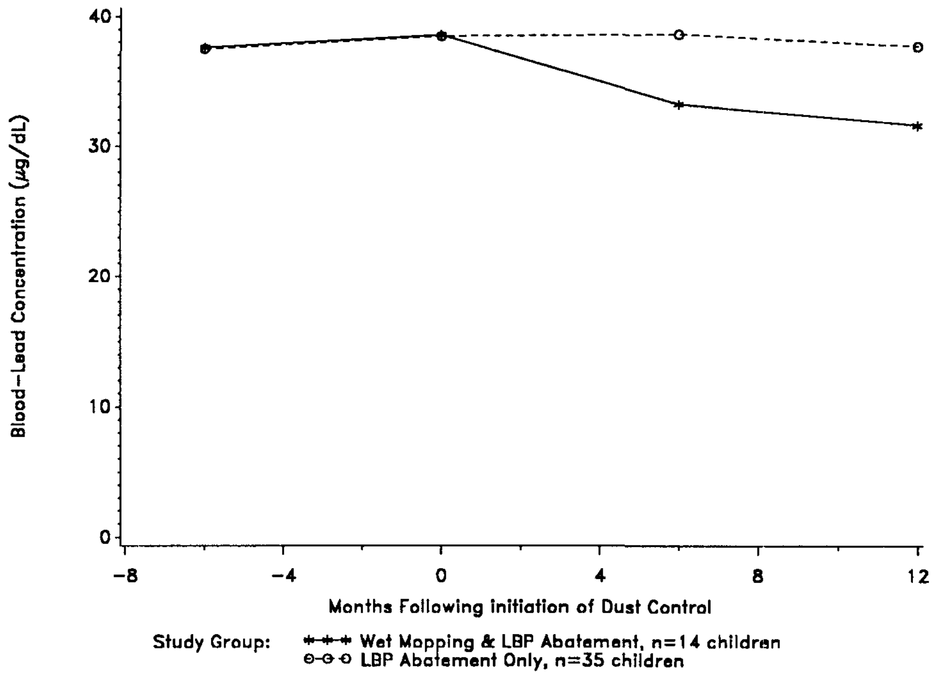

Figure 3-2. **Arithmetic mean blood-lead concentration (µg/dL) since abatement by study group (Baltimore Dust Control Study).**

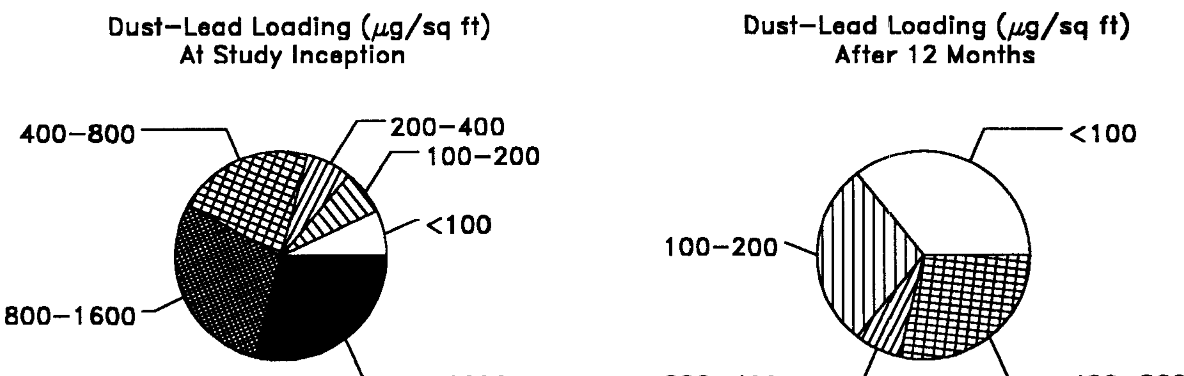

Figure 3-3. **Percentage of experimental homes with arithmetic mean dust-lead loadings (µg/ft^2) in the defined range (Baltimore Dust Control Study).**

3.1.2 1982 St. Louis Retrospective Paint Abatement Study

This 1982 study (Copley, 1983) sought to demonstrate a significant difference between the children living in abated environments after lead hazard intervention compared to children still exposed to lead hazards. The comparison was made among children measured to have a blood-lead concentration greater than 25 μg/dL. These children were enrolled in the St. Louis Health Division Childhood Lead Poisoning Prevention Program. The intervention entailed the abatement of the lead-based paint hazard, identified using XRF, within the residence. Surfaces with peeling or broken lead-based paint were enclosed, replaced, or had their lead-based paint removed. No extensive clean-up procedures necessarily accompanied the abatement. Blood-lead concentration measurements were collected during routine venipuncture screening.

A retrospective study compared those blood measurements which identified the child as lead poisoned to follow-up samples collected 6 to 12 months following the initial identification. A total of 102 children had sufficient samples collected to allow this comparison. Follow-up blood-lead concentrations in children whose lead hazards had been abated were found to be an average of 11.29 μg/dL lower than their initial levels (Figure 3-4). Blood-lead levels decreased on average only 1.24 μg/dL for children whose hazards had not yet been abated. The difference in these mean decreases was statistically significant ($p<0.001$).

The results indicated that abatement of lead-based paint hazards did significantly reduce the lead burden being borne by children with elevated blood-lead levels. The magnitude of the mean reported difference between initial and follow-up samples is impacted by the varying amount of time that passed between the sample collections and their timing relative to the abatement.

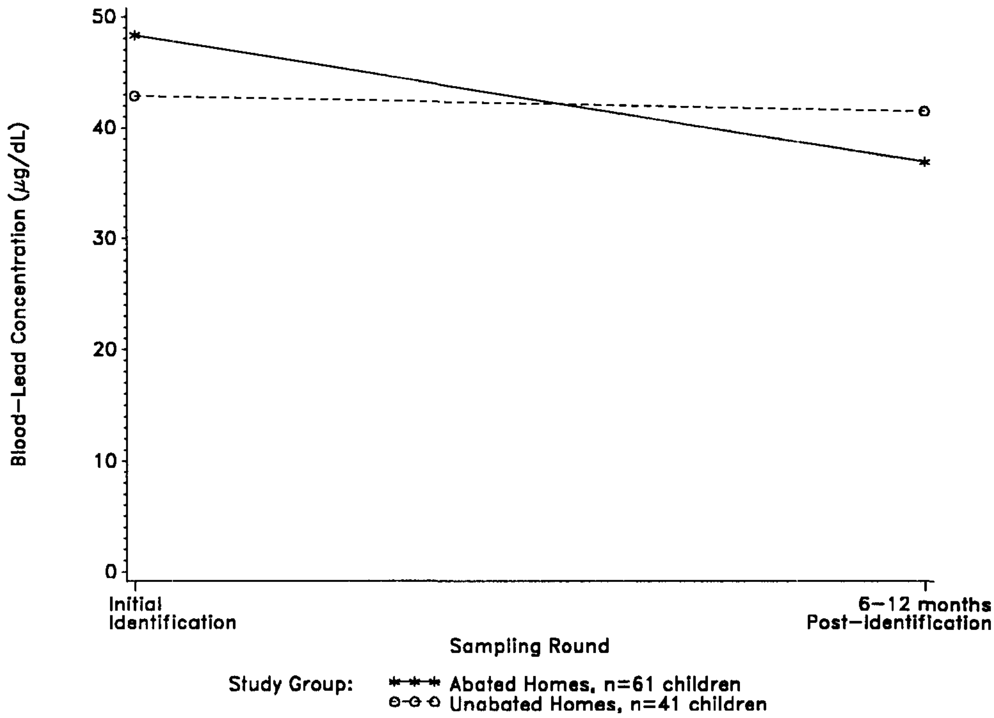

Figure 3-4. Pre- and post-identification arithmetic mean blood-lead concentration (µg/dL) by status of residence abatement (1982 St. Louis Retrospective Paint Abatement Study).

3.1.3 Baltimore "Traditional"/"Modified" Paint Abatement Study

The goal of this 1984-1985 study (Farfel and Chisolm, 1990) was to evaluate the health and environmental impact of "traditional" and "modified" Baltimore practices for the abatement of lead-based paint. The study examined children residing in 71 residences abated in urban Baltimore (53 traditional abatements, 18 modified abatements). Prior to abatement, all the residences had multiple interior surfaces coated with lead-based paint and housed at least one child with a blood-lead concentration greater than 30 µg/dL. "Traditional" Baltimore abatement practices called for addressing deteriorated paint on surfaces up to 4 ft from the floor, and all hazardous paint on accessible surfaces which may be chewed on. Paint with a lead content greater than 0.7 mg/cm^2 by XRF or 0.5% by weight by wet chemical analysis was determined hazardous. Open-flame burning and sanding techniques commonly were used to remove hazardous paint. Modified abatement procedures included the use of heat guns for paint removal and the repainting of abated surfaces. In clean-up including wet mopping with high-phosphate detergent, vacuuming with standard shop vacuums, and disposal of debris off-site. Clean-up following traditional abatement procedures typically entailed at most dry sweeping. Dust samples were obtained using a alcohol-treated wipe within a defined area template (1 ft^2). Blood samples were collected via venipuncture.

Serial measurements of lead in interior house dust (lead loading), and children's blood-lead concentration were collected. Average increases of 1200 $\mu g/ft^2$ in floor dust-lead loadings were measured immediately following traditional abatements (usually within 2 days) on or in close proximity to abated surfaces (Figure 3-7), with 10-100 fold changes at individual sites. Dust-lead levels measured after modified abatements were an average of 360 $\mu g/ft^2$ higher than pre-abatement levels. Thus, modified abatement procedures resulted in elevated floor dust-lead loadings, but not to the extent seen for traditional practices. At 6 months post-abatement, average dust-lead loadings were 65 $\mu g/ft^2$ higher than pre-abatement loadings for traditional abatements and 28 $\mu g/ft^2$ higher than pre-abatement loadings for modified abatements.

Pre- and post-abatement blood-lead concentrations were available for 46 children who lived in the abated residences and had not yet undergone any chelation therapy. The post-abatement samples were collected within one month following the completion of the abatement activities. For traditional abatements, average blood-lead levels in 27 children rose 6.84 $\mu g/dL$ (from 36.88 $\mu g/dL$ to 43.72 $\mu g/dL$) while a rise of only 1.03 $\mu g/dL$ (from 34.40 $\mu g/dL$ to 35.43 $\mu g/dL$) was observed for 19 children exposed to modified abatements (Figure 3-5). Moreover, a large number of children required chelation therapy. Six months after abatement, a subset of 29 children (14 traditional, 15 modified) who had not undergone any chelation therapy exhibited blood-lead concentrations (mean, 30.67 $\mu g/dL$) that were not significantly different from their pre-abatement levels (mean, 32.53 $\mu g/dL$). The 6-month results should be viewed with caution, since blood-lead levels were available for relatively few non-chelated children six months after abatement, primarily due to the large number of children requiring chelation therapy.

Despite the implementation of improved practices, modified abatements, like traditional abatements, did not result in any long-term reductions of levels of lead in house dust or the blood of children with elevated pre-intervention blood-lead concentrations.

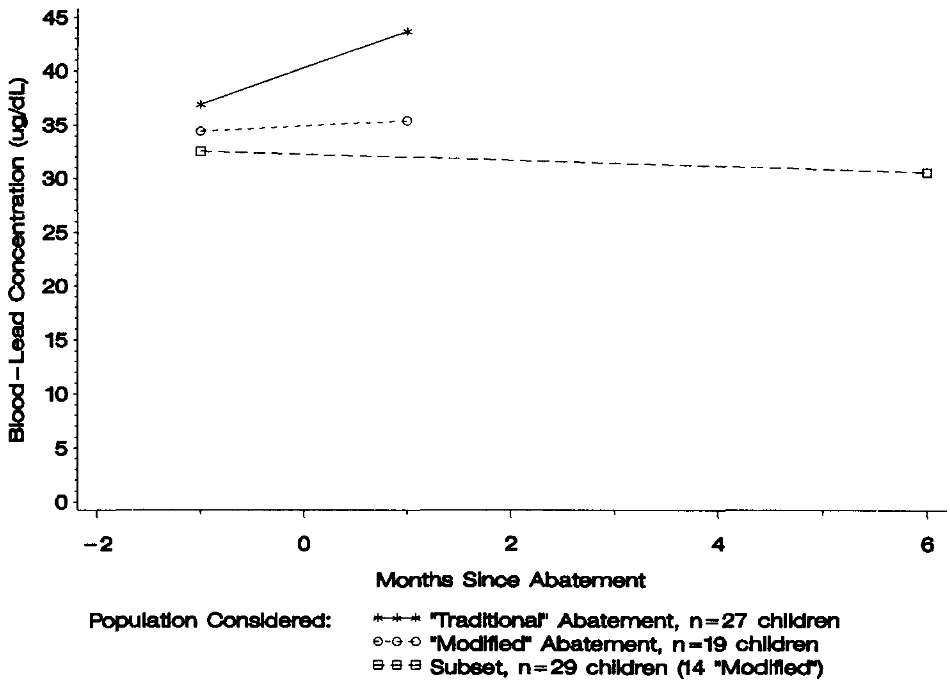

Figure 3-5. Arithmetic mean blood-lead concentration (μg/dL) post-abatement by population considered (Baltimore "Traditional"/"Modified" Paint Abatement Study).

3.1.4 Boston Retrospective Paint Abatement Study

This 1984-1985 study (Amitai et al., 1991) sought to evaluate the extent to which the lead poisoning of children is exacerbated during the abatement of lead-based paint within their residence. The study population consisted of 114 children ranging in age from 11 to 72 months (median age of 24 months) with at least one blood-lead concentration (above 25 μg/dL) obtained prior to deleading, one blood-lead sample collected during deleading, and one blood-lead determination following the completion of the deleading process. The deleading process consisted of the removal or permanent coverage of any paint with a lead content greater than 1.2 mg/cm^2 which was loose and peeling (at any height), or present on chewable surfaces accessible to a child (below 4 ft). Clean-up using wet washing with tri-sodium phosphate (TSP) was stressed, but not uniformly performed following the abatement. Blood-lead concentration measurements were collected via venipuncture.

The mean blood-lead level in the 114 children rose 5.7 μg/dL during deleading and then fell 8.6 μg/dL approximately 2 months following the completion of the deleading activities (Figure 3-6). The statistically significant ($p < 0.05$) decrease in mean blood-lead concentration post-deleading is due in part to 42 children who underwent chelation therapy between the mid- and post-deleading measurements.

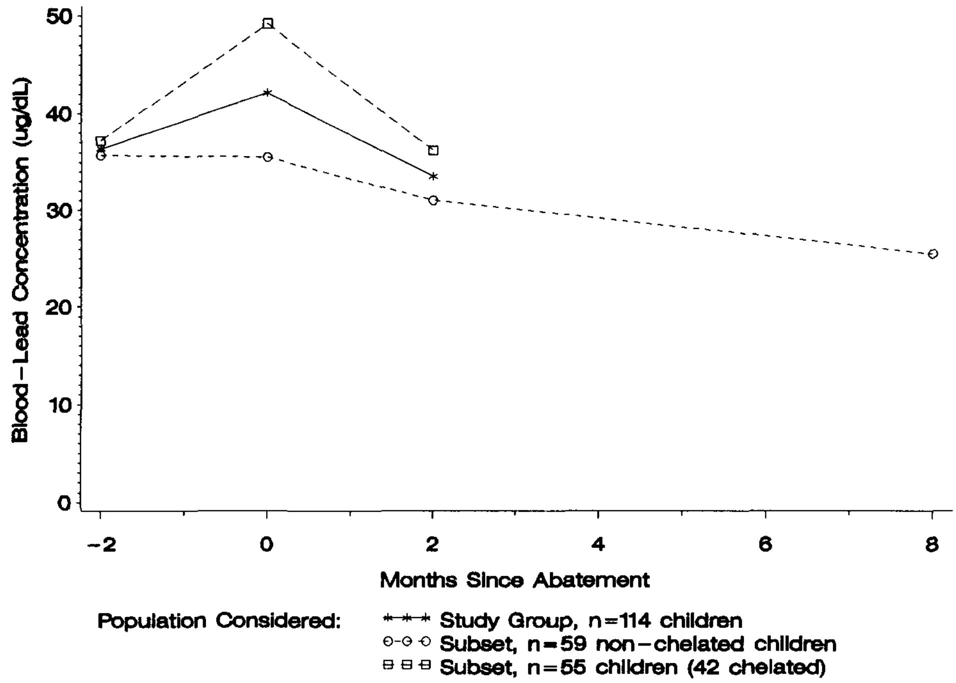

Figure 3-6. **Arithmetic mean blood-lead concentration (μg/dL) post-abatement by study population considered (Boston Retrospective Paint Abatement Study).**

In an effort to determine the effect of deleading activities alone, a subset of 59 children who underwent no chelation therapy were examined. In this subset, an additional follow-up measure was collected 236 to 264 days after completion of the deleading work. There was no evidence of a change in mean blood-lead concentration during deleading. However, blood-lead levels fell an average of 4.5 μg/dL at the post-deleading collection (approximately 2 months) and fell an additional 5.5 μg/dL by the follow-up (approximately 8 months) deleading collection (Figure 3-6). Caution is warranted when considering the results for the non-chelated children. By excluding children whose blood-lead levels rose (the children were already bordering the point where chelation therapy was appropriate), the declines in blood-lead concentration are not altogether surprising.

For 80 of the children, the specific method of deleading was available. Blood-lead levels in affected children were considerably elevated by dry scraping and sanding methods (mean increase in 41 homes of 9.1 μg/dL) and torches (35.7 μg/dL in 9 homes). By comparison, children exposed to encapsulation, enclosure, or replacement abatement procedures (12 homes) experienced a mean decrease of 2.25 μg/dL in their blood-lead burden during deleading. The study's results indicated that deleading may produce a significant, transient elevation of blood-lead in many children. It was most dangerous if accomplished with the use of torches, sanding, or dry scraping. The deleading may have been efficacious long-term, however, in that blood-lead concentrations declined significantly 2 months after deleading.

The stability of blood-lead levels prior to deleading activities was characterized for a subset of 32 children who had two blood samples prior to deleading. The mean blood-lead concentration rose from 35.4±1.3 μg/dL to 36.0±1.1 μg/dL during the interval between these samples (73±23 days), however, this change was not statistically significant ($p > 0.5$).

3.1.5 Baltimore Experimental Paint Abatement Studies

These studies (Farfel and Chisolm, 1991; USEPA, 1987; Farfel, el al., 1994) sought to demonstrate and evaluate experimental lead-based paint abatement practices developed in response to the inadequacies uncovered for traditional Baltimore abatement procedures (see Section 3.1.3). The literature examines two distinct sets of dwellings in urban Baltimore that were abated according to the experimental method.

The first study (Farfel and Chisolm, 1991) evaluated the short-term efficacy (up to 9 months) of the experimental abatement procedures in six older dwellings, built in the 1920s, that received abatements in 1986-1987 as part of a pilot study examining the experimental procedures. Each dwelling was a two-story six-room row home in poorly maintained condition with multiple lead-based paint hazards. Four of the residences were vacant, two housed lead-poisoned children.

The second study (Farfel, el al., 1994) evaluated the longer-term efficacy (1.5 to 3.5 years) of the experimental abatement procedures in 13 dwellings, which had received experimental abatements by local pilot projects between 1988 and 1991. At least 6 pairs of pre- and immediately post-abatement dust-lead loading measures, taken from the same locations, were available for each dwelling. The dwellings were occupied and had not undergone major renovations since those associated with the experimental abatement. Dust lead samples were collected in the 13 dwellings during December 1991 and January 1992, in the same locations, where possible, that had been sampled pre- and immediately post-abatement.

The experimental abatement procedure called for the floor to ceiling abatement of all interior and exterior surfaces where lead content of the paint exceeded 0.7 mg/cm^2 by XRF or 0.5% by weight by wet chemical analysis. Lead-contaminated dust was contained and minimized during the abatement, and extensive clean-up and disposal activities were utilized. Alcohol-treated wet wipes were used to collect dust-lead loading samples from household surfaces within each residence. In addition, surface soil samples were collected at the 13 dwellings in the second study.

In the 6 homes from the first study, serial measurements of lead in interior dust were made immediately before abatement, during the abatement, after the final clean-up, and 1, 3, and 6 to 9 months following the abatement. Floor dust-lead loadings immediately post-abatement were an average of 390 $\mu g/ft^2$ lower than pre-abatement levels (Figure 3-7). By 6 to 9 months following the abatements, average levels had decreased a further 74 $\mu g/ft^2$. The dust-lead loading monitoring before, during, and after the abatement activities also provided information on the effectiveness of particular measures. All floor and window treatments were associated with significant ($p < 0.05$) decreases in dust-lead loading over time. Results also suggested that window replacement may have been more effective in reducing dust-lead loading than stripping the lead-based paint. In addition, vinyl floor coverings may have produced lower dust-lead loadings than sealing old wooden floors with polyurethane.

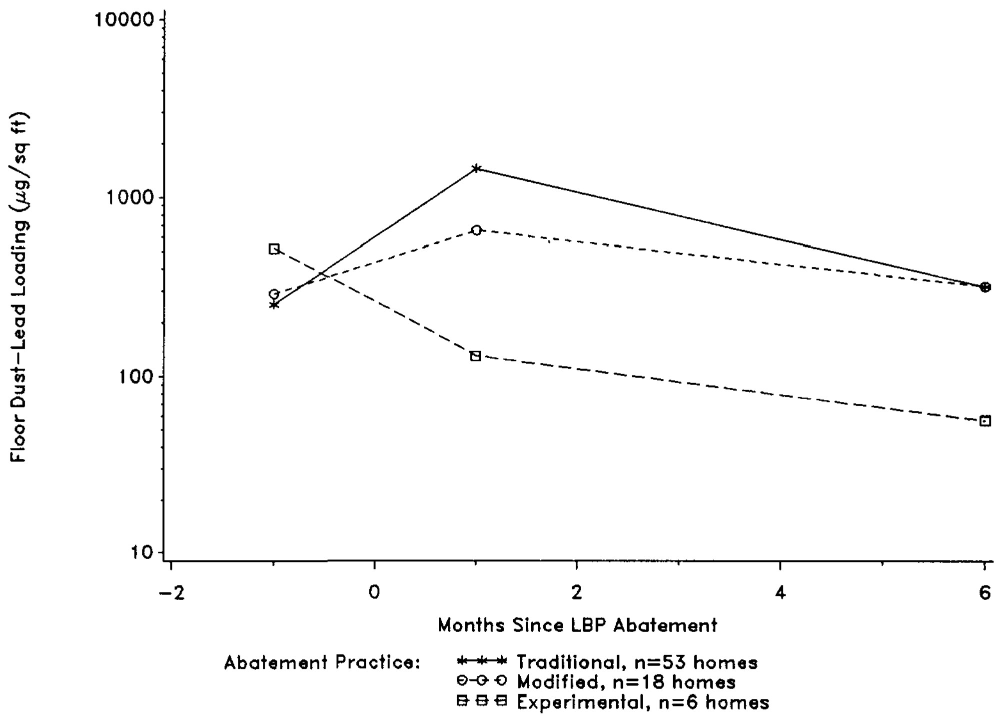

Figure 3-7. Geometric mean floor dust-lead loading ($\mu g/ft^2$) post-abatement by abatement practice performed (Baltimore "Traditional"/"Modified" and Experimental Practices Studies).

In the 13 homes considered in the second study, geometric mean PbD levels 1.5 to 3.5 years post-abatement were significantly less than pre-abatement levels, despite some reaccumulation of lead in dust. The geometric mean floor dust-lead loading was 40.9 $\mu g/ft^2$ 1.5 to 3.5 years post-abatement, compared with the pre- and immediately post-abatement levels of 254 $\mu g/ft^2$ and 13.9 $\mu g/ft^2$, respectively. Similarly, the geometric mean window sill dust-lead loading was 103 $\mu g/ft^2$ 1.5 to 3.5 years post-abatement, compared with the pre- and immediately post-abatement levels of 1041 $\mu g/ft^2$ and 13.0 $\mu g/ft^2$, respectively. Greater reaccumulation was observed for window wells, where the geometric mean dust-lead loading was 600 $\mu g/ft^2$ 1.5 to 3.5 years post-abatement, compared with the pre- and immediately post-abatement levels of 14214 $\mu g/ft^2$ and 34.4 $\mu g/ft^2$, respectively. Seventy-eight percent of all dust-lead loading measurements 1.5 to 3.5 years following intervention were within Maryland's interim post-abatement clearance standards (200 $\mu g/ft^2$ for floors, 500 $\mu g/ft^2$ for window sills, and 800 $\mu g/ft^2$ for window wells); twenty-one of the 39 readings above the clearance levels were from window wells. Soil-lead concentration was not found to be a significant factor in explaining the change in dust-lead levels.

The results suggest that comprehensive lead paint abatement is associated with longer-term as well as short-term control of residential dust-lead hazards. The experimental methods resulted in substantial reductions in interior surface dust-lead levels immediately post-abatement which were found to persist throughout a 6 to 9 month post-abatement period. Dust-lead levels were not uniformly reduced to desired levels, particularly on window sill and window well surfaces that were abated using paint removal methods by the 1.5 to 3.5 year post-abatement measures, however, 78% of all readings remained below target levels. The magnitude of the decline in dust-lead loadings following abatement may have been exaggerated in the first study since vacant units are likely to contain more dust than occupied units.

3.1.6 Central Massachusetts Retrospective Paint Abatement Study

This 1987-1990 retrospective study (Swindell et al., 1994; Charney, 1995) examined the effectiveness of résidential lead-based paint abatements as conducted between 1987 and 1990 in central Massachusetts. More stringent home deleading regulations were enacted in Massachusetts in 1988, during the period covered by the study. The sample population consisted of 132 children, 12 to 91 months of age, with a confirmed blood-lead concentration exceeding 25 $\mu g/dL$, and whose homes were abated between 1987 and 1990. In addition, the children had at least one venous blood-lead determination within 6 months prior to abatement and at least one venous blood-lead determination 2 weeks to 6 months after the completion of abatement. Children who received chelation therapy during that time, or who moved during the study period, were excluded from the study. Although a venous blood-lead level above 25 μg/dL was a criterion for this retrospective study, blood-lead concentrations immediately prior to abatement were less than 25 μg/dL for some children. In these cases, the authors suggest that the pre-abatement measure might have reflected some early abatement or education effects.

Abatements prior to 1988 consisted of the removal or permanent coverage of any paint with a lead content greater than 1.2 mg/cm^2 which was loose or peeling, or present on chewable surfaces accessible to the child (below 4 ft). No standard abatement methods, dust-control measures, or cleanup procedures were mandated. The 1988 regulations required licensing of abatement contractors (after completing a 3-day course and passing a certifying exam), specifically prohibited torching or machine sanding of paint, permitted only hand-scraping and replacement as removal methods, and required all occupants to vacate the dwelling during the entire abatement and cleaning process. There were no dust samples required after abatement, but the mandated cleanup entailed vacuuming all surfaces with a high-efficiency particle air (HEPA) filter vacuum, followed by wet-mopping and sponging with a trisodium phosphate cleaning solution, and then a second HEPA vacuuming.

Children's blood-lead concentration measures at most 6 months prior to initiation of abatement were compared to the last measurement collected within one year following abatement. The specific timing of post-abatement measures ranged from 3 to 52 weeks after abatement. The mean blood-lead level for the 132 children declined significantly ($p < 0.001$) following abatement, from 26.0 μg/dL to 21.2 μg/dL. Figure 3-8 summarizes the magnitude of the documented changes in blood-lead concentrations. Although blood-lead levels declined in 103 children (78%) within one year of abatement, the proportion who experienced a decline varied with initial blood-lead levels: 32 of 33 children (97%) with initial blood-lead levels exeeding 30 μg/dL, 64 of 79 (81%) with initial levels between 20 μg/dL and 29 μg/dL, and only 7 of 20 (35%) with initial levels below 20 μg/dL experienced a decline following abatement. In fact, as shown in Figure 3-9, among children with initial levels below 20 μg/dL, mean blood-lead levels increased from 16.7 μg/dL to 19.2 μg/dL following abatement ($p=0.053$). The calendar year of abatement did not appear to significantly impact the measured declines. In 1987, before the regulations were enacted, 29 children experienced a mean decline of 5.3 μg/dL. This is comparable to mean declines of 5.7 μg/dL in 1988 ($n=48$) and 4.7 μg/dL in 1989 ($n=42$). The mean decline among 13 children whose residences were abated in

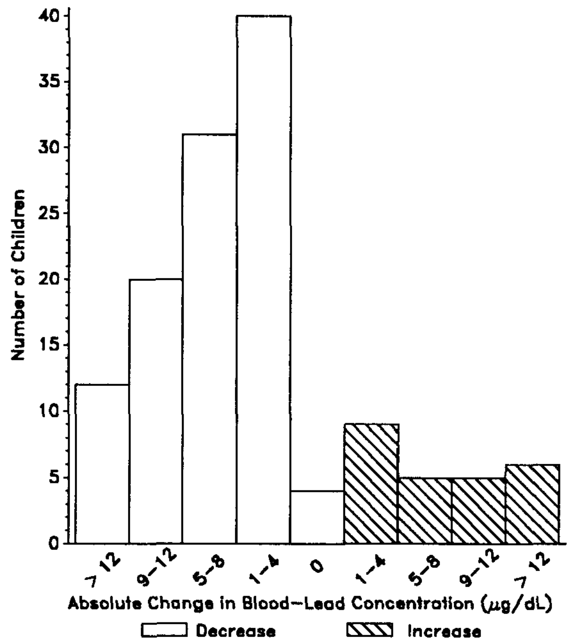

Figure 3-8. **Distribution of the absolute change in blood-lead concentrations (Central Massachussets Retrospective Paint Abatement Study).**

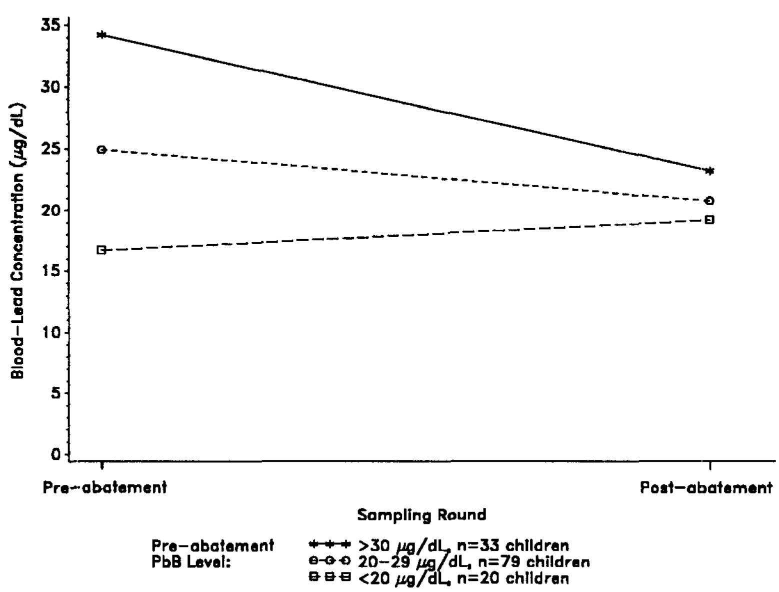

Figure 3-9. **Pre-abatement and post-abatement blood-lead concentration by pre-abatement blood-lead level (Central Massachusetts Retrospective Paint Abatement Study).**

1990 was influenced by two children whose levels increased markedly (from 16.0 and 17.0 μg/dL to 29.0 and 31.0 μg/dL). A 2.0 μg/dL median decline was measured for this group. Among 72 children with more than one pre-abatement measure, 40 children whose levels were declining (defined as a decrease greater than 5 μg/dL) prior to abatement exhibited only a modest further mean decline of 1.9 μg/dL. A more significant mean decline of 8.2 μg/dL was observed for the 32 children whose initial levels were relatively constant.

The study's results are consistent with other studies reporting declines in blood-lead concentrations following lead-based paint abatement. The significant decline among 32 children with stable levels prior to abatement suggests that regression to the mean cannot fully account for the observed decline. Moreover, the anticipated efficacy appears to depend on the child's initial blood-lead concentration. Children with high pre-abatement blood-lead concentrations were more likely to experience declines (and of greater magnitude) than children with lower pre-abatement blood-lead levels. In addition, it appears that stricter lead-based paint abatement regulations did not immediately result in significantly greater effectiveness. It also appears that even carefully performed abatements may result in post-intervention elevations in the blood-lead concentrations of children whose initial levels are below 20 μg/dL. Some caution in interpreting these results is warranted, however, because of the highly variable timing of the post-abatement measures. The children's blood-lead concentrations were measured anywhere between 3 and 52 weeks following completion of the abatement. Seasonal and age variation in blood-lead concentrations could significantly impact the observed decline, depending upon the period of time between the measures and the season in which the measures were collected.

3.1.7 Seattle Track-In Study

This study (Roberts et al., 1991) sought to determine the extent to which low cost dust-control measures successfully lowered household dust-lead loading. Forty-two homes in Seattle and Port Townsend, Washington, built before 1950 formed the population studied from 1988-1990. The three abatement procedures considered were strictly low-cost dust reduction procedures, namely, use of a vacuum cleaner with an agitator bar in normal cleaning, removal of shoes at the entrance to the residence, and installation of walk-off mats. Dust samples were collected from rugs within the residence using a Hoover Convertible vacuum cleaner. Soil samples were scraped from within 1 ft of the residence's foundation.

The study employed step-wise regression analysis to assess which factors determine the dust-lead loading within a residence. Significant associations were found between log transformed dust-lead loading and removing shoes at the door and the presence of a walk-off mat (e.g., hall carpet in an apartment building). Lower fine dust-lead levels (sieved before analysis) were found in homes where the residents removed their shoes (29 $\mu g/ft^2$) and/or used a walk-off mat (54 $\mu g/ft^2$) compared to those in homes whose residents did not (994 $\mu g/ft^2$).

The occupants of three homes tested in the study began removing their shoes upon entry for at least 5 months prior to the collection of a second dust-lead measurement from their carpets. In addition, the occupants of one of these homes installed walk-off mats at both entrances and began vacuuming twice weekly. The geometric mean dust-lead loading fell from 1588.6 $\mu g/ft^2$ to 23.2 $\mu g/ft^2$ in these homes.

The data suggested that controlling external soil and dust track-in by removing shoes and/or using a walk-off mat reduced the lead exposure from house dust. Lacking any blood measurements, it was difficult to assess the impact these interventions may have had on childhood lead exposure.

3.1.8 <u>1990 St. Louis Retrospective Paint Abatement Study</u>

This 1989-1990 study (Staes et al., 1994) attempted to assess, via a retrospective cohort study, the effectiveness of lead-based paint abatement in reducing children's blood-lead levels. The sample population consisted of children under 6 years of age who were identified by the St. Louis City Health Department as having a blood-lead concentration of at least 25 $\mu g/dL$, and residing in dwellings with lead-based paint hazards. The intervention entailed the abatement of the lead-based paint hazard, identified using XRF, within the residence. Surfaces with peeling or broken lead-based paint were enclosed, replaced or had their lead-based paint removed. No extensive clean-up procedures necessarily accompanied the abatement. The blood-lead concentrations were collected via venipuncture.

The geometric mean blood-lead concentration among the 189 children selected was 33.6 $\mu g/dL$. Seventy-one of these children, 49 whose homes were abated and 22 whose homes had not been abated, had blood-lead measures 10-14 months following the initial diagnosis. The geometric mean blood-lead concentration of the 49 children from abated dwellings decreased by 23%, from 34.9 to 26.7 $\mu g/dL$. This decline (Figure 3-10) was significantly greater ($p=0.07$) than the 12% reduction, from 35.1 to 30.9 $\mu g/dL$, observed among the 22 children residing in unabated dwellings.

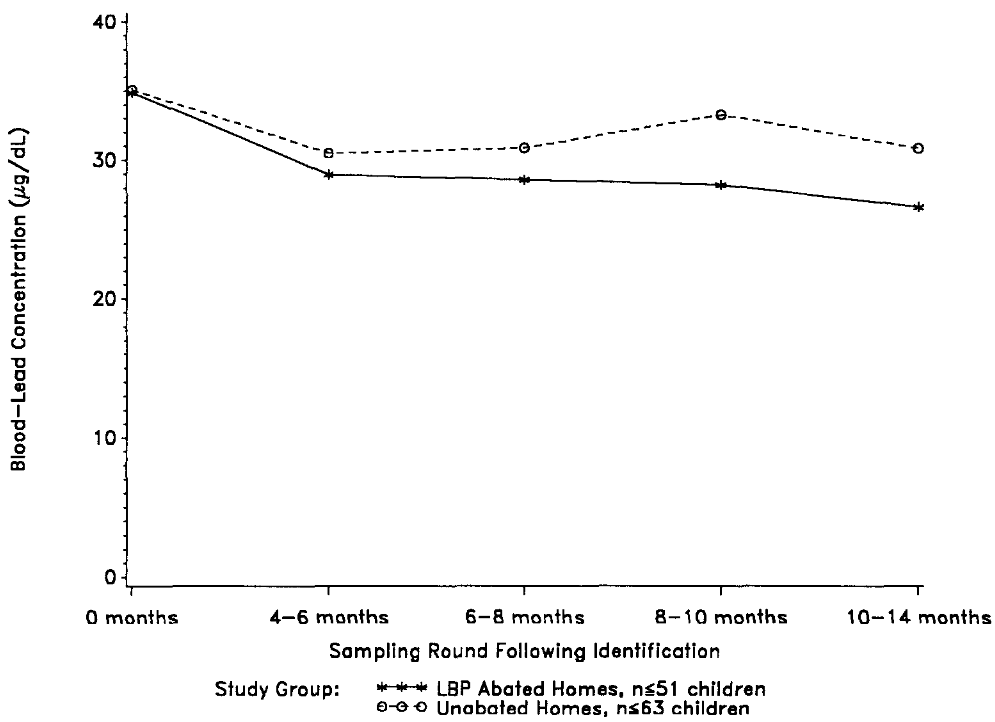

Figure 3-10. Pre- and post-identification arithmetic mean blood-lead concentration (µg/dL) by status of residence abatement (1990 St. Louis Retrospective Paint Abatement Study.)

A multiple linear regression model predicting the change in geometric mean blood-lead concentration at 10-14 months following diagnosis was fitted. The dwelling's abatement status at the time of the follow-up blood sample (e.g., abated or unabated) and whether the blood-lead level at diagnosis exceeded 35 µg/dL were statistically significant ($p<0.10$) factors in the analysis. The geometric mean blood-lead concentration of children residing in abated dwellings was estimated to decrease 13% (95% CI, -25% to 1%) more than that of children residing in unabated dwellings. Moreover, the geometric mean blood-lead concentration of children with an initial blood-lead concentration ≥35 µg/dL was estimated to decline by 17% (95% CI, -27% to -5%) more than that of children with lower blood-lead concentrations.

For lead-poisoned children in St. Louis, the decline in geometric mean blood-lead concentration was greater for children whose dwellings underwent lead-paint hazard abatement than for children whose dwellings did not. The magnitude of the efficacy appears to depend upon the child's initial blood-lead concentration. The reported differences between initial and follow-up samples were impacted by individual differences in the amount of time that passed between the sample collections and their timing relative to the abatement. Many of the follow-up measures were collected less than six months following the abatement.

3.1.9 Boston Three-City Soil Abatement Study

This 1989-1991 project (Weitzman et al., 1993; Aschengrau, et al., 1994) assessed whether a significant reduction (≥ 1000 ppm) in the concentration of lead in residential soil will result in a significant decrease (≥ 3 μg/dL) in the blood-lead concentration of children residing at the premises. A total of 152 children were enrolled, each satisfying the following criteria: (1) less than or equal to 4 years of age, (2) blood-lead concentration between 10 and 20 μg/dL with no history of lead poisoning, and (3) a minimum median residential soil-lead concentration of 1500 ppm. The project employed four intervention procedures: (a) interior paint stabilization by removing peeling or chipping paint, (b) interior dust abatement via wet mopping and HEPA vacuuming, (c) soil removal (to a depth of 6 inches) and replacement, and (d) interior and exterior lead-based paint abatement. Dispersal of soil during the abatement was retarded by wetting the soil, preventing track-in by workers, containing the abatement site with plastic, and washing all equipment. Extensive environmental media and body burden samples were collected: composite core soil samples; vacuum dust samples; first draw water samples; interior and exterior paint assessment via portable XRF; venipuncture blood samples; and, hand-wipe samples.

Each child enrolled was randomly assigned to one of three experimental groups: Study (54 children), Comparison A (51 children), or Comparison B (47 children). During Phase I, the Study Group received interior paint stabilization, interior dust abatement, and soil abatement. Comparison Group A received interior paint stabilization and interior dust abatement. Comparison group B residences received only interior paint stabilization. During Phase II, which began approximately 12 months after the Phase I interventions, both comparison groups received soil abatement and all three experimental groups were offered lead-based paint abatement. Environmental media and body burden samples were collected at various times surrounding these intervention activities.

During Phase I, the average blood-lead concentrations in all three experimental groups decreased at the first (6 months) post-abatement measurement (Figure 3-11). The statistically significant decreases were: 2.9 μg/dL for Study, 3.5 μg/dL for Comparison A, and 2.2 μg/dL for Comparison B. The following increases in average blood-lead concentration were recorded between

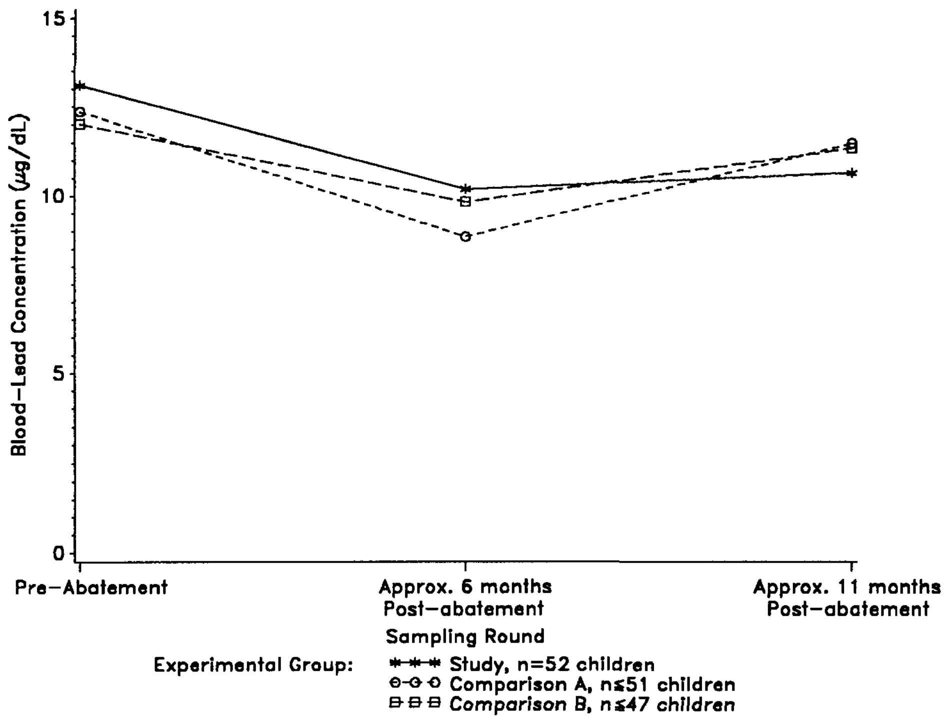

Figure 3-11. Arithmetic mean blood-lead concentration (µg/dL) across sampling rounds and experimental groups, Phase 1 (Boston 3-City Soil Abatement Project).

the first and second (11 months) post-abatement measurements: 0.5 µg/dL for Study, 2.6 µg/dL for Comparison A, and 1.5 µg/dL for Comparison B. The increases for the two comparison groups were significantly different from zero. The mean dust-lead levels from hand wipe samples for all groups followed a similar pattern, though they exhibited considerably greater variability.

By the end of Phase II, 91 children were still participating and living at the same premises as when they were enrolled. Of these children, 44 received both soil and lead-based paint abatement, 46 received only soil abatement, and 1 refused both interventions. Although some premises underwent lead-based paint deleading during Phase II, no results on the additional efficacy of lead-paint abatements were reported.

For children whose residence underwent soil abatement only, mean blood-lead concentrations decreased by 2.44 µg/dL for 52 children in the Study Group, 5.25 µg/dL for 18 children in Comparison Group A, and 1.39 µg/dL for 13 children in Comparison Group B, between pre- and post-intervention measures (Figure 3-12). Blood-lead measures were taken an average of 10 months post-abatement for the Study Group (during Phase I) and an average of 9 months post-abatement for the comparison groups (during Phase II).

A repeated measures analysis was conducted using a restricted sample of 31 children from Comparison Group A (N=18) and Comparison Group B (N=13) who received only soil abatement during Phase II and who had blood-lead measures at the beginning of Phase I, the end of Phase I, and the end of Phase II. Study Group data were excluded for lack of a control period. Mean blood-lead concentrations decreased by 0.64 μg/dL during Phase I (before the soil abatements) and another 3.63 μg/dL during Phase II (a 33.9% decline overall). A trend in the magnitude of the decline in blood-lead levels was apparent, with larger declines observed in children with larger initial blood-lead levels.

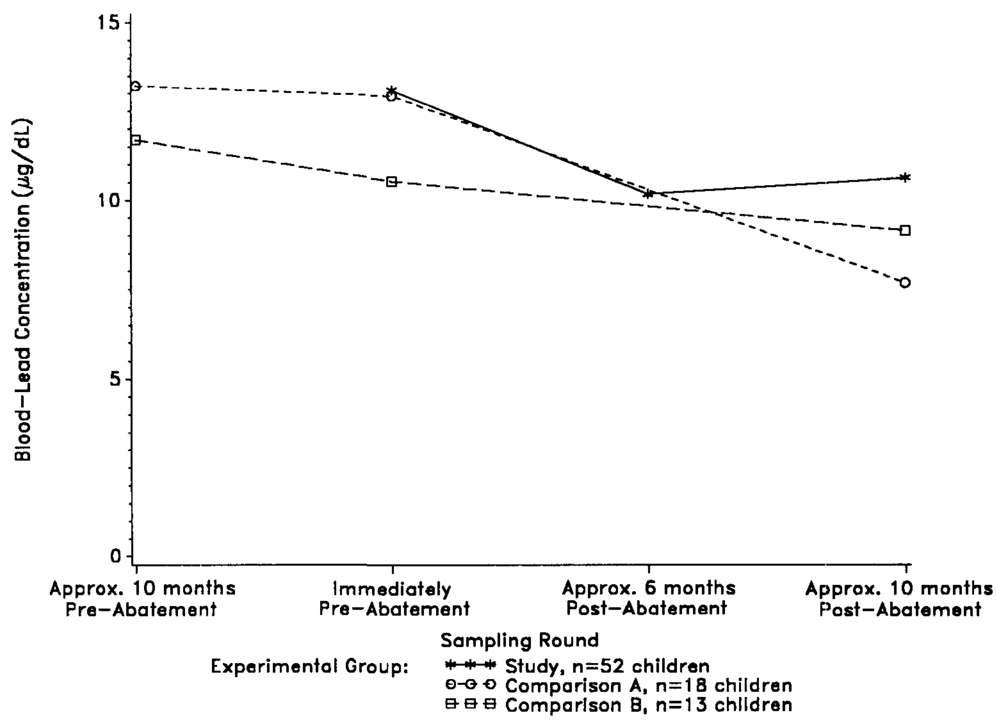

Figure 3-12. Arithmetic mean blood-lead concentration (μg/dL) across sampling rounds and experimental groups, Phase I and II (Boston 3-City Soil Abatement Project).

The decline in median soil-lead concentration among Study group residences immediately post-abatement averaged 1790 ppm (range: 160 ppm to 5360 ppm). Although many yards had evidence of recontamination both at 6-10 months and 18-22 months post-abatement, follow-up median soil-lead concentrations were generally less than 300 ppm (Figure 3-13). Similar results were observed for the comparison groups following the soil abatements in Phase II. Dust-lead loadings were less consistent. Composite floor dust-lead loadings declined significantly during the study. Comparable declines were seen in all three groups during Phase I, despite Comparison Group B not receiving any interior house dust abatement. Mean floor dust-lead loadings were relatively unchanged for Comparison Groups A and B (P=0.95 and 0.15, respectively) during Phase II, despite the soil abatement. By 18-22 months post-abatement, mean levels in the Study Group had risen, but remained still significantly below initial levels (P=0.02). Mean window well dust-lead loadings declined in Comparison Group A following the soil abatement, but rose in the Study Group and in Comparison Group B.

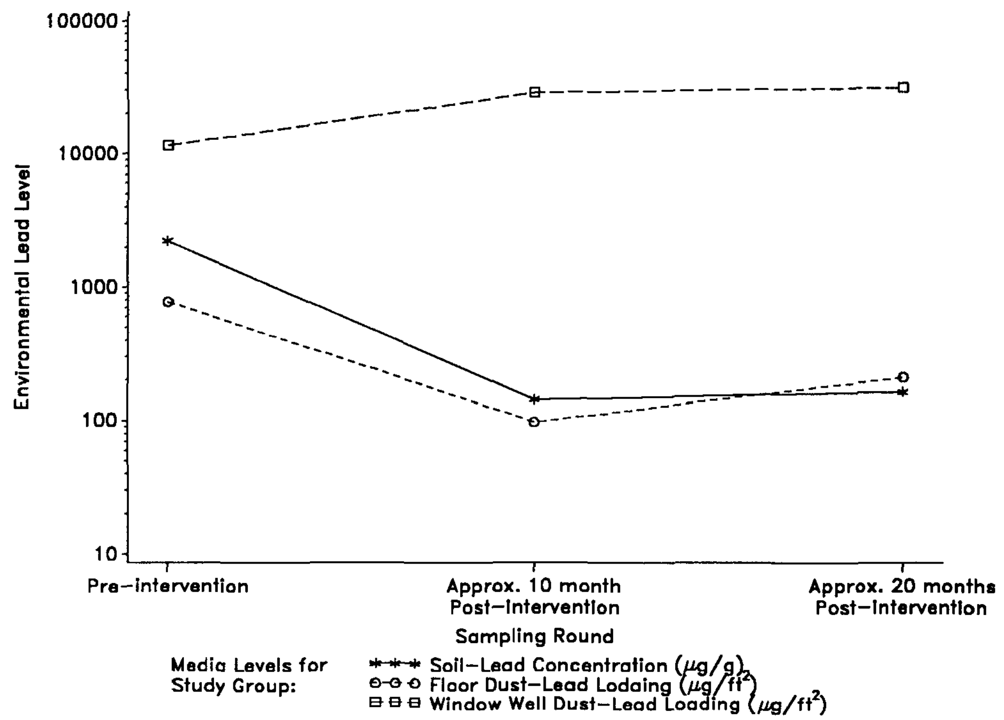

Figure 3-13. Arithmetic mean environmental lead level (for Study Group) across sampling rounds (Boston 3-City Soil Abatement Project).

These results suggested that abatement of lead-contaminated soil around homes may result in a modest decline in blood-lead levels. The reported declines, however, may be influenced by seasonal variation in blood-lead levels. Seasonal variations in blood-lead concentrations of comparable magnitude have been cited in other studies conducted in Boston and Milwaukee (Kinateder and Menton, 1992; Schultz, 1993). In addition, relatively few children were available for the Phase II analysis, which introduces the possibility of bias in the estimated declines due to low participation at follow-up. Moreover, since no control populations were available for the Phase II results, it is difficult to assess their larger declines.

3.1.10 HUD Abatement Demonstration (HUD Demo) Study

This study (HUD, 1991; HUD, 1990) was designed to determine and evaluate the overall suitability and effectiveness of various methods of lead-based paint abatement. These methods were tested in 1989-1990 in 172 FHA-foreclosed, single family housing units in seven urban areas: Baltimore, Washington, D.C., Seattle, Tacoma, Indianapolis, Denver, and Birmingham. Six abatement procedures were employed: (1) encapsulation by sealing the surfaces with durable coatings, (2) abrasive removal of lead-based paint using mechanical removal equipment, (3) hand-scraping with a heat gun to loosen and remove the lead-based paint, (4) chemical removal of lead-based paint using a chemical stripper, (5) enclosure or covering the surface, and (6) removal of contaminated building components and replacing with new or deleaded components. Because of the diversity of housing components containing lead-based paint, it was generally true that no single abatement method could be used uniformly throughout a given housing unit. Therefore an abatement strategy, consisting of decision rules for choice of abatement method, was randomly assigned to each house. The method used to characterize the unit abatement strategy was always the first-choice method and was used on all components to the extent feasible. Second, third and fourth choice methods were also specified for each strategy. XRF devices were used to identify components covered by paint with a lead content greater than 1.0 mg/cm^2. These components were abated in the houses selected for the study. Following completion of the abatement, the units were extensively cleaned using HEPA vacuums and wet washing with TSP. Surfaces were wet wiped to obtain dust-lead loading samples within a defined area and core soil samples were collected. No blood-lead measures were collected, however, since the units were vacant prior to abatement.

Pre-abatement dust-lead loadings generally were not collected. Once the lead-based paint had been abated and the area cleaned, clearance wipe samples were collected to verify acceptable dust-lead levels (Figure 3-14). The resulting dust-lead loading was compared to the appropriate standard in the HUD Guidelines (HUD, 1990) -- 200 μg/ft^2 for floors, 500 μg/ft^2 for window sills, and 800 μg/ft^2 for window wells. On average, 80% of floor wipe samples, 85% of window sill samples, and 65% of window well samples passed the initial clearance test by measuring below the appropriate standard. Additional cleaning, or other measures, were required for surfaces that did not pass. There were significant differences in failure rates among the different abatement methods. The highest failure rates were generally for components abated using chemical stripping (22.7%, 24.1%, and 45.7% for floors, sills, and wells) and heat gun removal (28.8%, 24.4%, and 44.5% for floors, sills, and wells).

With the exception of abrasive sanding (the machines kept clogging), all the methods were successfully implemented. To do so, however, required varying degrees of effort. Chemical stripping and heat gun methods had lower success rates in meeting the HUD Guidelines than did encapsulation, enclosure and replacement methods.

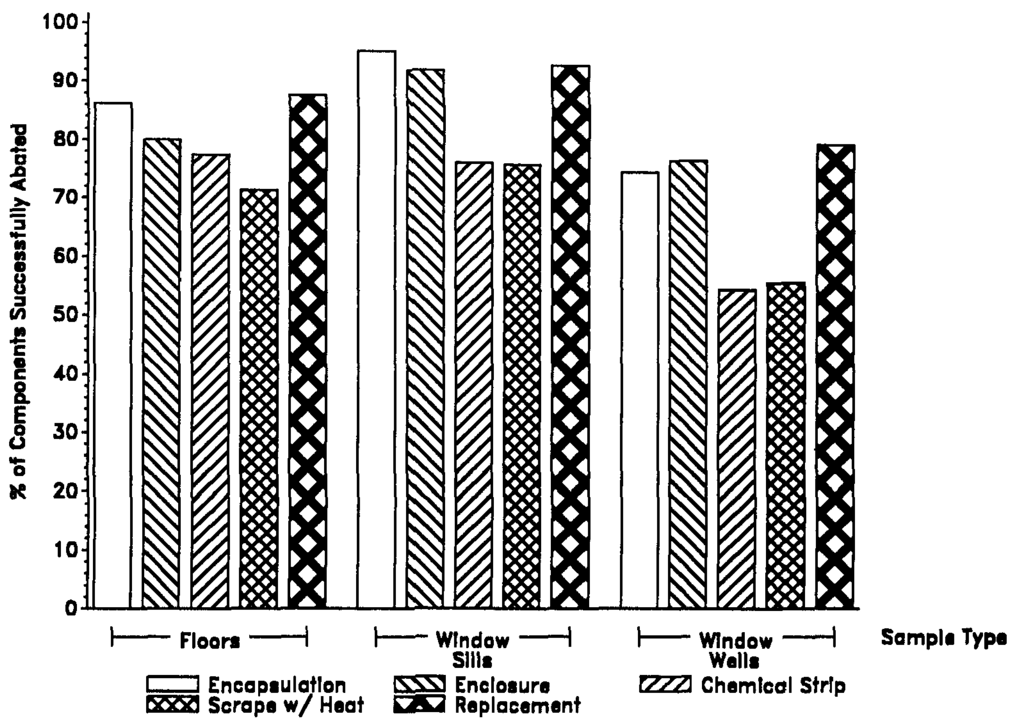

Figure 3-14. Percentage of components successfully abated to HUD Guidelines Standards by abatement method and sampling location (HUD Demo Study).

3.1.11 Comprehensive Abatement Performance (CAP) Study

The 1992 CAP study (Buxton et al., 1994) assessed the long-term effectiveness of two lead-based paint abatement strategies: (1) encapsulation and enclosure methods and (2) removal methods. Fifty-two FHA foreclosed, single family residences in Denver, Colorado, were examined. Thirty-five of the residences were abated using the aforementioned methods as part of the HUD Demonstration study. Each house was primarily classified according to the abatement category (i.e., encapsulation/

enclosure versus removal methods) accounting for the largest square footage of interior abatement. The remaining 17 residences were unabated homes identified in the HUD Demonstration as containing little or no lead-based paint. At the time of the environmental sampling approximately 1.5 to 2 years following the abatements, the units were occupied. Vacuum dust-lead levels were measured at the interior and exterior entryways, floor perimeters, window sills, window wells, and air ducts of each residence. Core soil samples were collected at the foundation, entryway, and boundary of the home. No blood-lead measures were collected because the units were not reoccupied until several months after their abatement.

The CAP Study found geometric mean lead concentrations in abated houses to be significantly higher than those in unabated houses only at sampling locations where no abatement was performed (Figure 3-15). Specifically, the differences were statistically significant for dust in the air ducts and for soil at the foundation and boundary areas. Geometric mean dust-lead loadings on floors and exterior entryways were also significantly higher in abated houses than unabated houses, but these differences were attributed to higher dust loadings. It should be noted that both floor and window sill geometric mean dust-lead loadings in abated houses were found to be below their respective HUD interim standards of 200 and 500 $\mu g/ft^2$. Geometric mean floor dust-lead loadings were also below the EPA guidance (EPA, 1994) level of 100 $\mu g/ft^2$. In contrast, geometric mean window well dust-lead loadings in both abated and unabated houses were found to be well above the HUD value of 800 $\mu g/ft^2$.

Lead levels were somewhat higher, though not significantly higher, in houses abated by encapsulation/enclosure methods than in houses abated by removal methods. When interpreting these results it should be noted that encapsulation/enclosure houses typically had larger amounts of abatement performed than removal houses. Therefore, the differences in lead levels noted above may have been largely a result of the more severe initial conditions in encapsulation/enclosure houses.

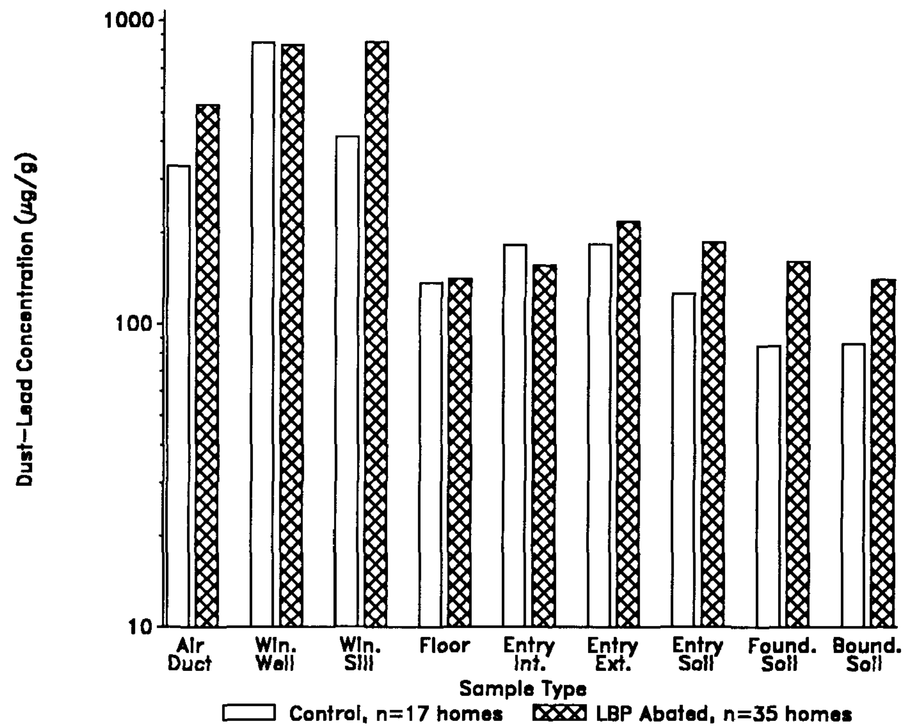

Figure 3-15. Estimated geometric mean dust-lead and soil-lead concentration (µg/g) in typical abated and unabated homes by sampling location (CAP Study).

3.1.12 Milwaukee Retrospective Paint Abatement Study

This on-going study is examining the effectiveness of the lead-based paint abatement strategies implemented in the Milwaukee area in 1989-1992 (Schultz, 1993). Damaged, painted surfaces with lead loadings exceeding 1.0 mg/cm^2 were abated. Abatement method and clean-up procedures varied depending upon the practices of the particular abatement contractor. Only preliminary results from this study were available, but are worth noting. Blood-lead concentrations were collected from 104 children before and (mostly) 3 to 12 months after the lead-based paint abatement. The arithmetic mean blood-lead concentration reduced from 34 µg/dL pre-abatement to 26 µg/dL post-abatement, a 24% decline.

3.1.13 New York Chelation Study

This 1989-1990 study (Rosen et al., 1991; Markowitz et al., 1993; Ruff et al., 1993) was an effort to ascertain the efficacy of a particular chelation therapy procedure on moderately lead-poisoned children. Two hundred and one children with blood-lead levels between 25 and 55 μg/dL were administered a lead mobilization test (LMT) to determine whether chelation therapy might prove effective. Children with a positive LMT underwent chelation therapy. For all children enrolled, visual and XRF inspections of the paint in their residences were performed. Residences of 89% of the children had sufficient lead-based paint to warrant an abatement. In addition to taking blood-lead measurements, the authors measured cognitive ability and bone-lead content, using the net corrected photon count (CNET) by L-XRF for the latter.

The reported results for this study emphasized overlapping subsets of the enrolled population. The first set of analyses examined a subset of 174 children (71 chelated, 103 control). Six to seven weeks following enrollment, average blood-lead levels among the 103 non-chelated children had fallen 2.5 μg/dL (mean at enrollment, 29.0 μg/dL) and average bone-lead levels had fallen 3.3 CNET (mean at enrollment, 125.3 CNET). The second set of analyses considered a subset of 154 children (61 chelated, 93 control). Cognitive index rose 3.6 points (from 79.0 to 82.6), on average, among a subset of 126 children (both chelated and non-chelated) six months following enrollment. The authors concluded that cognitive index increased approximately one point for every 3 μg/dL decrease in blood-lead level. The third subset was of 59 children, 30 of whom were non-chelated. Mean blood-lead levels among the 30 non-chelated children had fallen 6 μg/dL by 6 weeks post-enrollment (from 29 μg/dL to 23 μg/dL) and fell an additional 2 μg/dL (to 21 μg/dL) by 24 weeks post-enrollment (Figure 3-16). This represents a 28% decline as compared to an average decline of 37% among the chelated children (39.5 μg/dL to 25 μg/dL). Mean bone-lead levels did not change among the non-chelated children during this time period.

Though sifting through the various subsets is difficult, there was evidence that lead-based paint abatement lowered blood-lead levels. Furthermore, the authors concluded that the results suggest an association between declines in blood-lead levels and positive health outcomes (in addition to the lowered blood-lead concentration).

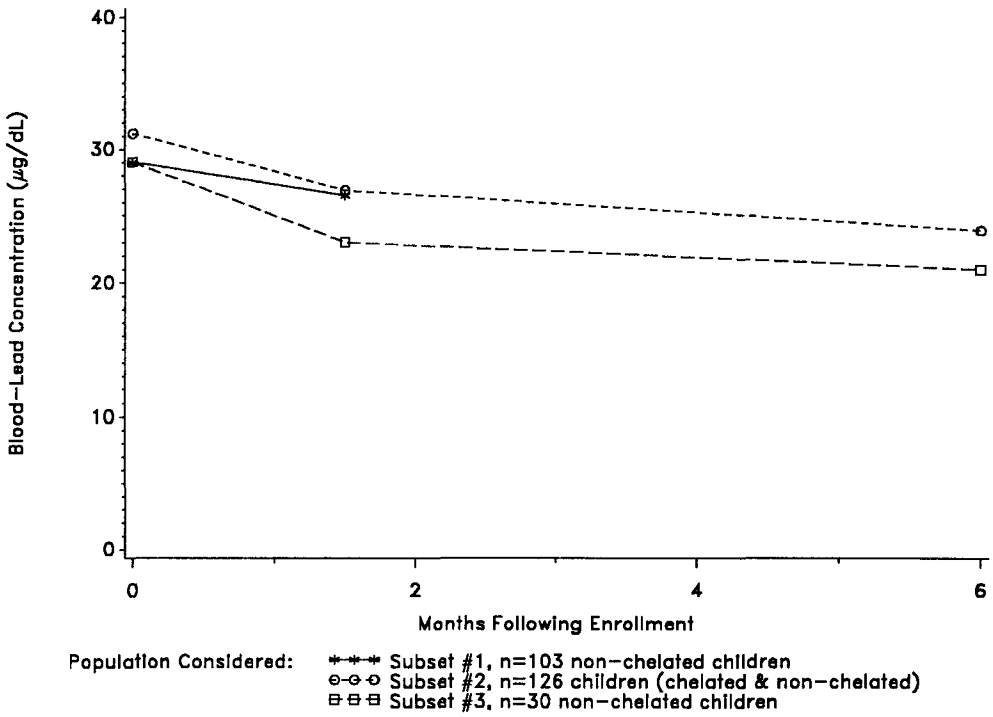

Figure 3-16. Arithmetic mean blood-lead concentration (µg/dL) by population considered (New York Chelation Study).

3.1.14 Milwaukee Retrospective Educational Intervention Study

This study assessed the effectiveness of in-home education efforts in Milwaukee in 1991-1994. The sample population consists of 431 children, 6 years of age and under, who were identified by the Milwaukee Health Department as having blood-lead concentrations between 20-24 µg/dL, had a follow-up blood-lead measure, and had not moved before the follow-up measure. Of these, 195 children received an in-home educational visit and had a follow-up blood-lead measure after the in-home visit. The control group of 236 children did not receive a health department in-home visit, either because they were identified before the educational outreach program was in place, or because the family could not be contacted after three attempts. The in-home educational visits were conducted by para-professionals. Visits lasted approximately one hour and included education on nutrition and behavior change, as well as housekeeping recommendations to reduce childhood lead exposure. Both venous and capillary blood-lead measurements were used. Follow-up measurements were collected

2-15 months after initial blood-lead measures. Blood-lead concentrations were adjusted for the effects of age and seasonal variations.

Blood-lead levels decreased for 154 of the 195 (79%) children who received an in-home educational visit, compared to 124 of the 236 (53%) children in the control group. The arithmetic mean blood-lead concentration for the Educational Outreach group declined by 18%, from 22 μg/dL to 18 μg/dL, compared to the Control group decline of 5%, from 22 μg/dL to 21 μg/dL. The difference between these declines is highly statistically significant ($p=0.001$). These results imply that educational intervention is effective in reducing children's blood-lead levels, although blood-lead concentrations usually remained above 10 μg/dL.

3.1.15 Granite City Educational Intervention Study

This 1991 study (Kimbrough, 1992, 1994; IDPH, 1995) included an effort to evaluate the efficacy of educational interventions in reducing blood-lead concentrations in exposed individuals. Children, under six years of age and recruited in Granite City, Illinois, constituted the sampled population. Most homes in the community were built prior to 1920 and contained lead-based paint. In addition, a secondary lead smelter had been in operation until 1983. Extensive educational efforts were aimed at the children and families exposed to elevated levels of lead in the surrounding environment. Instruction included identifying where lead-based paint was commonly found, explaining available abatement procedures, detailing how to perform house cleaning procedures, and reviewing hygienic procedures for young children. Venous blood samples, soil samples, dust samples from within the residence, tap water samples, and an assessment of the lead content in interior paint were collected. When possible, follow-up blood-lead measures were collected from children with elevated blood-lead levels four months and twelve months after the initial sample.

Blood-lead levels were initially measured during the months of August and September 1991. Of the 490 children under age 6, 78 (16%) had blood-lead levels greater than 9 μg/dL. Of these, 5 had levels greater than 25 μg/dL. Between the initial and four month samples, the families of children with elevated blood-lead levels received extensive counseling in the prevention of lead exposure. Mean blood-lead concentrations decreased significantly from an initial level of 14.6 μg/dL to 7.8 μg/dL at the four month post-abatement measurement, but rose again to 9.6 μg/dL by the twelve month measure, as shown in Figure 3-17. Despite the rise in blood-lead levels, the 12 month averages remained significantly below initial levels.

In addition, four month follow-up blood-lead concentrations were significantly lower than initial levels in a small number of older children with elevated blood-lead levels. For 7 children aged 6 to 14 years, the arithmetic mean decrease was 5.9 μg/dL, and for 3 children age 15 years or older, blood-lead levels decreased 7.0 μg/dL.

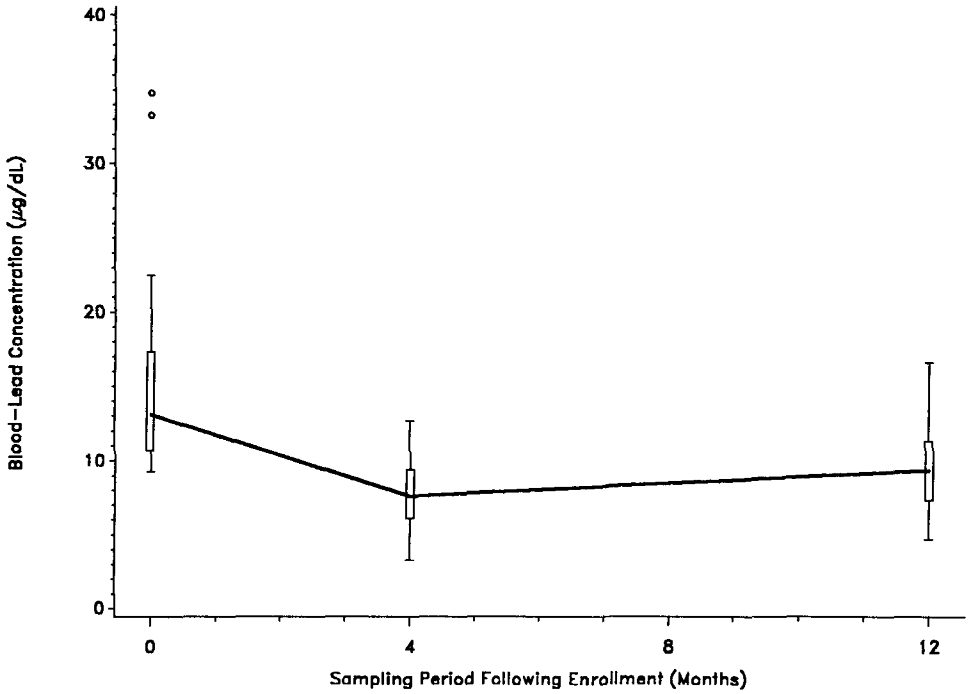

Figure 3-17. Initial and follow-up arithmetic mean blood-lead concentration (μg/dL) (Granite City Educational Intervention Study).

The absolute decrease and percent decrease at the four month and twelve month follow-up measures are shown in Figure 3-18 for a subgroup of 24 children under age 6 with initially elevated blood-lead concentrations, for whom both follow-up measures were available. The magnitude of the decrease in blood-lead concentration appears to be directly related to the magnitude of the initial blood-lead concentration, as shown in Figure 3-19.

The striking declines in blood-lead levels provide evidence of the effectiveness of educational efforts. The full implications of these declines in blood-lead concentration, however, could not be ascertained since no measurements were collected for a control group of children. The one year follow-up results for the subset of children suggest that seasonal variation alone does not account for the observed decline in blood-lead concentrations, but may very well explain why the levels at 4 months were lower than those at 12 months.

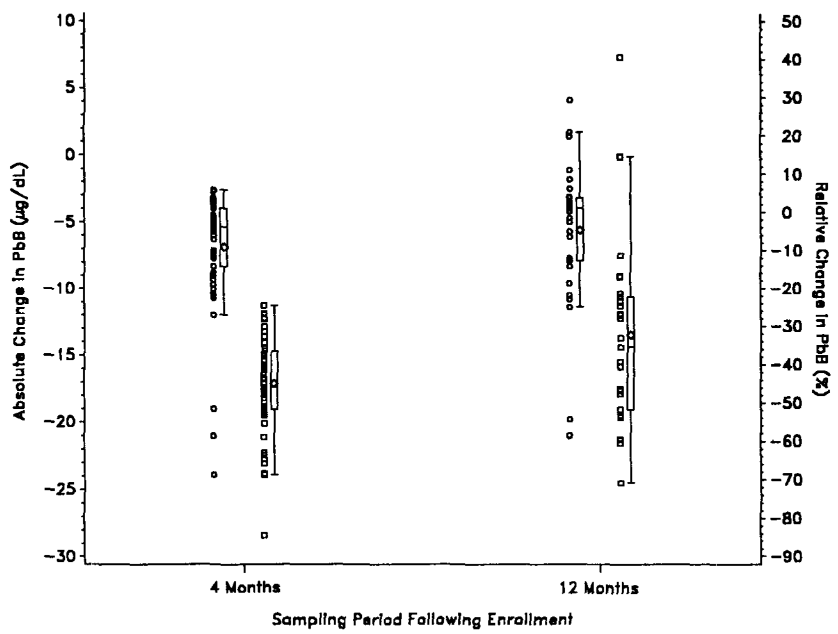

Figure 3-18. **Absolute (on left) and percent change in blood-lead concentrations at 4-month and 12-month follow-up (Granite City Educational Intervention Study).**

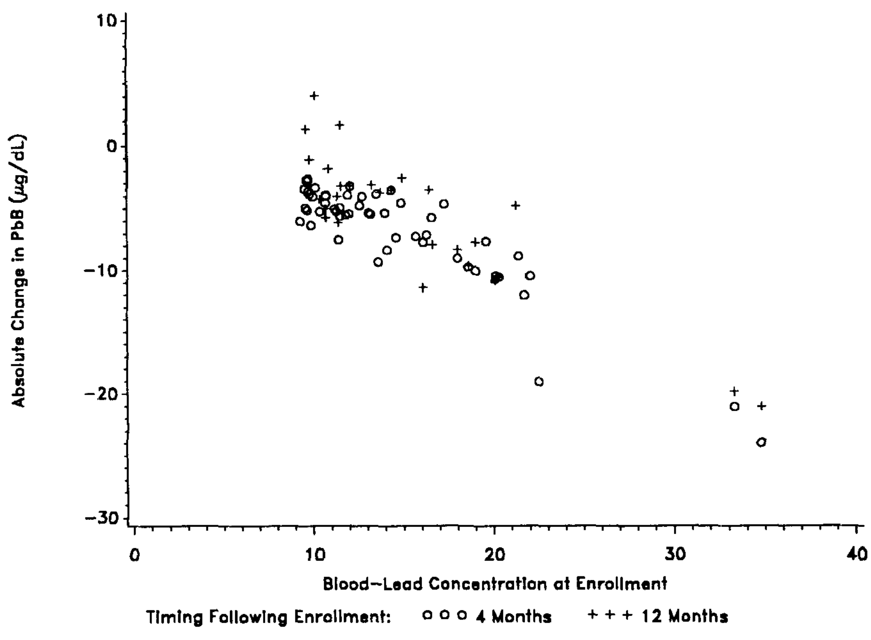

Figure 3-19. **Change in blood-lead concentration at 4-month and 12-month follow-up plotted against initial blood-lead concentration (Granite City Educational Intervention Study).**

3.1.16 Milwaukee Prospective Educational Intervention Study

This study sought to assess the effectiveness of in-home educational efforts by an educational outreach program established in Milwaukee in 1991 (Schultz, 1995). Children between 9 and 72 months of age were identified by the Milwaukee Health Department in June 1993. The children selected for this prospective study had a blood-lead concentration greater than 20 μg/dL but had not received a in-home educational visit in the previous year. Nor had their dwelling been abated in the previous year. Two groups of children were prospectively examined.

(a) Standard In-home Educational Outreach.

The Educational Outreach group consisted of 54 children whose initial blood-lead concentration was between 20-24 μg/dL. Follow-up blood-lead measures were collected an average of 2 months after the in-home visit for these children. For comparison, a control group of 122 children was selected from those previously identified in the Milwaukee Retrospective Study (see Section 3.1.14), whose follow-up blood-lead measurement was taken within approximately 3 months of the initial measurement. Children received in-home educational visits conducted by para-professionals. Visits lasted approximately one hour and educated the families on nutrition, behavior change, and housekeeping recommendations to reduce childhood lead exposure. Both venous and capillary blood-lead measurements were used. Blood-lead levels were adjusted for the effects of seasonal variation.

Only preliminary results from this study were available, but are worth noting. Both the Educational Outreach and Control groups had initial mean blood-lead levels of approximately 22 μg/dL. On average, a significantly greater decline between initial and follow-up blood-lead concentration was observed for the Educational Outreach group than for the Control group. The decline was about 3 μg/dL more in the Educational Outreach group.

(b) Pre-abatement Educational Outreach.

The Pre-abatement Educational Outreach group consisted of 28 children whose initial blood-lead concentration was between 25 μg/dL and 40 μg/dL. Lead-based paint abatements were required for these children, but had not been implemented at the time of the in-home visit and follow-up blood-lead measurement. Follow-up blood-lead measures were collected 2-6 months after the initial measurement for the Pre-abatement Educational Outreach group. Children in the Pre-abatement Educational Outreach group received the same visit as the study (a), plus an additional visit from a

Public Health Nurse, who conducted a general health assessment of the child and family and also answered any questions about lead. In addition, a paint inspection was performed in all pre-abatement homes. Both venous and capillary blood-lead measurements were used, and blood-lead levels were adjusted for the effects of seasonal variation.

Again, only preliminary results from this study were available. Mean blood-lead concentrations for the Pre-abatement Educational Outreach group started at 29 μg/dL and declined by 19%. No control group was available for the pre-abatement educational outreach group, as extensive efforts were made to contact all families where children had blood-lead levels at or above 25 μg/dL. Approximately the same percentage decline in blood-lead levels was observed in both the Educational Outreach and Pre-abatement Educational Outreach groups. On average, larger absolute declines were observed in the Pre-abatement group, suggesting that greater declines on an absolute scale may be associated with higher initial blood-lead concentrations. This is consistent with results reported for other lead-hazard intervention methods.

The results of these studies imply that educational intervention is effective in reducing children's blood-lead levels, although blood-lead concentrations usually remained above 10 μg/dL.

3.2 SUMMARY OF SCIENTIFIC EVIDENCE

The available literature on lead hazard intervention efficacy focused on impeding the hand-to-mouth pathway of childhood exposure to environmental lead sources. The emphasis on this exposure pathway seems appropriate since it is recognized in the literature as the predominant pathway in young children (USEPA, 1986; CDC, 1991; ATSDR, 1988). The pathway may be disrupted by a variety of means including the abatement of lead-based paint, dust-lead level reduction procedures, and elevated soil-lead abatement.

The literature is limited in its scope. It only covers some of the many abatement types and methods used in practice. However, the studies suggest that both "in-place management" and "source isolation or removal" methods were at least partially effective in reducing blood-lead concentrations. There was no definitive evidence in the literature that one of these categories of methods was more efficacious than the other. Source isolation or removal methods often had an accompanying risk of at least short-term elevation of residents' blood-lead levels that must be factored into any summary of intervention efficacy. In-place management methods, in turn, usually required sustained effort to maintain their effectiveness.

A summary table for the identified lead intervention studies is presented in Table 3-1.

Summary tables for blood-lead concentration results and other body-lead burden results are presented in Tables 3-2 and 3-3, respectively. A summary of environmental media efficacy is displayed as Table 3-4. The 10 paint abatement studies examined all employed source removal or isolation methods to abate the lead-based paint hazard. The literature suggests that the efficacy of these methods depends in part on the safeguards employed to protect the occupants and their residential environment during abatement. In the 1984-1985 Boston Retrospective (Amitai et al., 1991) and 1984-1985 Baltimore Traditional/Modified (Farfel and Chisolm, 1990) Paint Abatement studies, average blood-lead levels were observed to increase 16% to 19%, on average, during abatement and remain elevated following the intervention. The levels in Baltimore were elevated one month following intervention, but in Boston they had decreased by two months post-abatement. In the case of the Baltimore study, the authors suggested that the increase stemmed from incomplete abatement or insufficient clean-up following the abatement. Dust-lead levels within the dwelling were exacerbated, which led the authors to the conclusion that environmental exposure had merely been shifted from one medium to another. In both the Boston and Baltimore studies, elevated blood-lead levels were associated particularly with the dry-scraping and heat-gun methods of source removal which were performed in 1984-1985.

In the Boston Retrospective study, lead-based paint abatement methods such as encapsulation, enclosure, and replacement were associated with an average reduction of 2 to 3 μg/dL in blood-lead concentrations. The results of the HUD Demo study (HUD, 1991; HUD, 1990) also suggest that clearance standards may be easier to meet via encapsulation and enclosure methods than via removal methods. The CAP study (Buxton et al., 1994) indicated that long-term interior dust-lead levels were somewhat higher, though not statistically higher, in encapsulation/enclosure homes than in removal homes. However, as was noted earlier, this may have been largely a result of the more severe initial conditions in encapsulation/enclosure houses. Still, in samples collected from floors and window sills, both types of abatement method resulted in 18 to 24 month follow-up dust-lead levels below HUD Guidelines (HUD, 1990) standards. Since the HUD Demo and CAP studies followed units that were vacant before abatement, no changes in residents' blood-lead levels were available.

Lead-based paint removal methods were shown to lower the blood-lead levels of inhabitants in the Boston Retrospective (Amitai et al., 1991), Central Massachusetts Retrospective (Swindell et al., 1994), 1982 St. Louis Retrospective (Copley, 1983), 1990 St. Louis Retrospective (Staes et al., 1994), New York Chelation (Rosen et al., 1991; Markowitz et al., 1993; Ruff et al., 1993), and Milwaukee (Schultz, 1993) studies. These studies reported 18 to 29% declines in the blood-lead concentration of affected residents. Comparable or larger declines post-intervention were identified for other body-lead burden measures in the New York Chelation (Rosen et al., 1991; Markowitz et al., 1993; Ruff et al., 1993) and 1982 St. Louis Retrospective (Copley, 1983) studies. The declines were manifest as soon as 6 weeks after abatement. The magnitudes of these reductions are less than the 80% potential discussed in Section 2.2. The remaining lead in the blood (20-29% declines leave about 3/4 still present) may be due to any number of reasons including the mobilization of bone-lead stores, the incomplete abatement of the lead-based paint and elevated dust-lead, and the potential for exposure from other micro-environments. Since the analysis discussed in Section 2.3 suggests bone-lead stores could not by themselves keep blood-lead levels elevated for even six months post-abatement, the latter reasons seem plausible as contributors to elevated blood-lead concentrations.

There is evidence that lead-based paint abatement, by itself, may not be fully effective because of the potential recontamination from unabated sources. In the CAP Study (Buxton et al., 1994) geometric mean lead concentrations in unabated air ducts and soils were found to be significantly higher in abated houses as compared to control houses. Moreover, geometric mean dust-lead loadings in window wells were above HUD Guideline levels (800 $\mu g/ft^2$) for both abated and control houses.

The two non-educational dust abatement studies primarily employed in-place management methods. It seems unlikely that these methods aggravate childhood lead exposure if performed improperly. Once such techniques are discontinued, however, the dust-lead hazard may return. The Baltimore Dust Control Study (Charney et al., 1983) focused on managing the dust-lead hazard after removing or isolating the lead-based paint hazard identified within the residence. The Baltimore study noted that, "in most homes the initially high [dust-lead] levels were again present within 2 weeks after the first visit" (Charney et al., 1983), although eventually dust-lead levels remained low between visits. Similarly, the one-time dust abatement and paint stabilization performed in the Boston 3-City Soil Abatement study (Weitzman et al., 1993) reduced window well dust-lead loadings for only a short period of time.

Regular, extensive dust-lead hazard management efforts by trained personnel produced an 18% decline in mean blood-lead concentration and a 29% decline in FEP concentration for affected residents; a control population exhibited only a 2% decline in mean blood-lead concentration (see Baltimore Dust Control study (Charney et al., 1983)). The Seattle Track-In study (Roberts et al., 1991) reported significantly lowered dust-lead levels after residents removed their shoes and used a walk-off mat (no blood-lead measures were collected).

Table 3-1. Summary Information Table for Identified Lead Intervention Studies

Primary Form of Abatement Studied	Study Title	Method of Abatement Employed: Source Isolation or Removal: Encap/ Enclo	Method of Abatement Employed: Source Isolation or Removal: Cmplt Rmvl	Method of Abatement Employed: Source Isolation or Removal: Partial Rmvl	Method of Abatement Employed: In-Place Management	Abatement Included Extensive Clean-Up	Sources Abated: Soil	Sources Abated: Dust	Sources Abated: Paint	Blood-Lead Measures Collected
Paint	1982 St. Louis Retrospective	●		●					●	●
	Baltimore Traditional/Modified			●					●	●
	Boston Retrospective	●		●		●			●	●
	Baltimore Experimental	●	●			●			●	
	Central Massachusetts Retrospective	●		●		●			●	●
	1990 St. Louis Retrospective	●		●					●	●
	HUD Demo Study	●	●			●			●	
	CAP Study	●	●			●			●	
	Milwaukee Retrospective LBP			●					●	●
	New York Chelation			●					●	●
Dust	Baltimore Dust Control*		●	●	●			●	●	●
	Seattle Track-In				●			●		
	Milwaukee Retrospective Educational				●			●		●
	Granite City Educational				●			●		●
	Milwaukee Prospective Educational				●			●		●
Soil	Boston 3-City	●	●	●	●	●	●	●	●	●

* These residences received partial lead-based paint abatements and complete abatements of lead-containing dust.

Table 3-2. Summary of Blood-Lead Concentration Results for Identified Lead Hazard Intervention Studies

Study	Group	Initial		1-6 Month Post-Intervention Follow-Up			>6 Month Post-Intervention Follow-Up		
		Sample Size	Mean Level (μg/dL)	Sample Size	Months Post-Intervention	Mean % Change	Sample Size	Months Intervention	Mean % Change
Baltimore Dust Control	Abated and Dust Control	14	39	14	6	-14%	14	12	-18%
	Abated	35	39	33	6	+1%	35	12	-2%
1982 St. Louis Retrospective	Abated	61	48	-	-	nc	61	6-12	-23%
	Unabated	41	43	-	-	nc	41	6-12	-3%
Baltimore "Traditional"/"Modified"	"Traditional"	27	37	27	1	+18%	-	-	nc
	"Modified"	19	34	19	1	+3%	-	-	nc
	Combined	29	33	-	-	nc	29	6	-6%
Boston Retrospective	Study	114	36	114	1	-8%	-	-	nc
	No Chelation	59	36	59	During	-13%	59	8	-28%
Central Massachusetts Retrospective	Abated	132	26	132	3-52 weeks	-18%	-	-	nc
1990 St. Louis Retrospective	Abated	-	na	-	-	nc	49	10-14(1)	-23%
	Unabated	-	na	-	-	nc	22	10-14(1)	-12%
Boston 3-City Phase I	Study	52	13	52	6	-22%	52	10	-19%
	Comparison A	51	12	48	6	-28%	49	10	-7%
	Comparison B	47	12	46	6	-18%	46	10	-6%
Boston 3-City Phase II	Comparison A	18	13	-	-	nc	18	9	-41%
	Comparison B	13	11	-	-	nc	13	9	-13%
Milwaukee Retrospective LBP	Study	104	34	-	-	nc	104	3-12	-24%
New York Chelation	No Chelation	103	29	103	1.5	-9%	-	-	nc
	No Chelation (Subset)	30	29	30	1.5	-21%	30	6	-28%

Table 3-2. Summary of Blood-Lead Concentration Results for Identified Lead Hazard Intervention Studies (Continued)

Study	Group	Initial		1-6 Month Post-Intervention Follow-Up			>6 Month Post-Intervention Follow-Up		
		Sample Size	Mean Level (μg/dL)	Sample Size	Months Post-Intervention	Mean % Change	Sample Size	Months Intervention	Mean % Change
Milwaukee Retrospective Education	Educational Outreach	195	22	195	2-15	-18%	-	-	nc
	Control	236	22	236	2-15	-5%	-	-	nc
Granite City Educational	Study	59	15	54	4	-45%	29	12	-32%
	Children with Complete Data	24	15	24	4	-47%	24	12	-40%
Milwaukee Prospective Education	Educational Outreach	54	22	54	2	-18%	-	-	nc
	Control	122	22	122	2	-5%	-	-	nc
	Pre-abatement Educational Outreach	28	29	28	2-6	-19%	-	-	nc

nc - Measurements were not collected during these time intervals.
na - Insufficient information is available in the literature to allow determination of these values.
(1) These measurements were collected 10-14 months following diagnosis of elevated blood-lead levels (and ensuing educational interventions). The timing of the abatements were not available.

Table 3-3. Summary of Other Body-lead Burden Results for Identified Lead Hazard Intervention Studies

Study	Measure	Group	Initial		1-6 Month Post-Intervention Follow-Up			>6 Month Post-Intervention Follow-Up		
			Sample Size	Mean Level	Sample Size	Months Post-Intervention	Mean % Change	Sample Size	Months Post-Intervention	Mean % Change
Baltimore Dust Control	FEP (μg/dL)	Abated and Dust Control	14	203	14	6	-22%	14	12	-29%
		Abated	35	231	33	6	-6%	35	12	-10%
1982 St. Louis Retrospective	ZPP (μg/dL)	Abated	61	119	--	--	--	61	6-12	-32%
		Unabated	41	99	--	--	--	41	6-12	-3%
New York Chelation	EP (μg/dL)	No Chelation (subset)	30	80	30	1.5	+2%	30	6	-48%
	Bone-lead (corrected net counts)	No Chelation (subset)	30	117	30	1.5	+3%	30	6	+3%

Table 3-4. Summary of Environmental Media Results for Identified Lead Hazard Intervention Studies

Study	Group	Media	Units	Initial				First Post-Abatement Measure				Second Post-Abatement Measure			
				No. of Houses	No. of Samples	Geom. Mean	Geom. SD	No. of Samples	Geom. Mean	Geom. SD	Timing Post-Abate.	No. of Samples	Geom. Mean	Geom. SD	Timing Post-Abate.
Baltimore "Traditional"/ "Modified" Paint Abatement Study	"Traditional" Paint Abatement	Floor Dust	μgPb/ft²	53	280	251	1.07	271	1440	1.10	48 Hrs	234	316	1.07	6
		Window Sill Dust	μgPb/ft²	53	249	1338	1.10	246	3595	1.12	48 Hrs	199	1542	1.13	6
		Window Well Dust	μgPb/ft²	53	150	15496	1.17	139	14353	1.14	48 Hrs	100	12468	1.19	6
	"Modified" Paint Abatement	Floor Dust	μgPb/ft²	18	82	288	1.18	50	650	1.21	48 Hrs	57	316	1.16	6
		Window Sill Dust	μgPb/ft²	18	95	1802	1.16	64	604	1.18	48 Hrs	66	1644	1.21	6
		Window Well Dust	μgPb/ft²	18	37	18274	1.31	24	8083	1.33	48 Hrs	32	24879	1.31	6
Baltimore "Experimental" Paint Abatement Study	"Experimental" Up to 9 Months	Floor Dust	μgPb/ft²	6	70	520	1.17	70	130	1.18	(1)	63	56	1.17	6
		Window Sill Dust	μgPb/ft²	6	34	4608	1.26	35	325	1.36	(1)	31	409	1.32	6
		Window Well Dust	μgPb/ft²	6	28	29422	1.31	31	938	1.33	(1)	24	1003	1.42	6

Table 3-4. Summary of Environmental Media Results for Identified Lead Hazard Intervention Studies (Continued)

Study	Group	Media	Units	Initial				First Post-Abatement Measure				Second Post-Abatement Measure			
				No. of Houses	No. of Samples	Geom. Mean	Geom. SD	No. of Samples	Geom. Mean	Geom. SD	Timing Post-Abate.	No. of Samples	Geom. Mean	Geom. SD	Timing Post-Abate.
Baltimore "Experimental" Paint Abatement Study	"Experimental" 1.5-3.5 Years	Floor Dust	$\mu gPb/ft^2$	13	42	254	--	47	13.9	--	(1)	71	40.9	--	18-42
		Window Sill Dust	$\mu gPb/ft^2$	13	53	1041	--	54	13.0	--	(1)	59	103	--	18-42
		Window Well Dust	$\mu gPb/ft^2$	13	31	14214	--	41	34.4	--	(1)	49	600	--	18-42
Boston[2] 3-City Soil Abatement Project	Study	Soil	$\mu gPb/g$	34	35	2206	1123	35	141	299	10	34	160	115	20
		Floor Dust	$\mu gPb/ft^2$	21	21	769	54	14	96	35	10	11	207	22	20
		Window Well Dust	$\mu gPb/ft^2$	19	19	11524	143	15	28773	75	10	11	31420	41	20
	Comparison A	Soil	$\mu gPb/g$	31	31	2358	1203	--	--	--	--	32	171	172	9
		Floor Dust	$\mu gPb/ft^2$	22	22	295	29	--	--	--	--	15	315	28	9
		Window Well Dust	$\mu gPb/ft^2$	22	22	28373	58	--	--	--	--	15	15417	92	9
	Comparison B	Soil	$\mu gPb/g$	26	26	2299	1129	--	--	--	--	26	180	127	9
		Floor Dust	$\mu gPb/ft^2$	22	22	261	45	--	--	--	--	12	295	27	9
		Window Well Dust	$\mu gPb/ft^2$	21	21	21487	63	--	--	--	--	12	37205	102	9

(1) Measurements were collected after clean-up procedures were completed.
(2) Arithmetic means and standard deviations are reported, instead of geometric means and standard deviations.

The three educational intervention studies also employed in-place management methods. In-home educational visits emphasized proper housecleaning methods to reduce dust-lead levels, improved hygiene habits to reduce hand-to-mouth lead exposure, and educated families on proper nutrition to reduce the health effects of elevated body-lead levels. No abatements were performed in the study homes. The Granite City Educational Intervention Study (Kimbrough et al., 1992, 1994) found a 32% drop in mean blood-lead level from extensive educational outreach (a drop from 15 μg/dL, on average). The implication of this decline was difficult to ascertain, however, since no measurements were collected for a control group of children. Both the Milwaukee Retrospective Educational Intervention Study (Schultz, 1994) and Milwaukee Prospective Educational Intervention Study (Schultz, 1994) reported 18% declines in blood-lead concentrations following in-home educational visits. The declines following educational intervention for these studies were significantly greater than declines observed in control children.

The one study of soil abatement employed both source isolation or removal methods and in-place management methods. The Boston 3-City Soil Abatement Study (Weitzman et al., 1993) removed and replaced soil exhibiting elevated lead levels, but also stabilized the peeling paint and wet mopped the interior dust. Soil-lead and floor dust-lead levels in the abated residences remained low post-abatement. Blood-lead concentrations among affected inhabitants oscillated after abatement, but did not return to pre-abatement levels. In fact, a modest decline of 1 to 2 μg/dL in average blood-lead concentration (19% of pre-abatement levels, on average) was reported approximately 1 year following the abatements in Phase I. Similar temporal variation in the average blood-lead levels of residents of unabated dwellings used as controls in the study was observed, with declines after 1 year of 7.1% and 5.6% for Comparison Groups A and B, respectively. In Phase I, the control residences underwent the same one-time paint stabilization procedure as the study residences. A subset of the comparison populations underwent soil abatement in Phase II, and exhibited 41% (Comparison Group A) and 13% (Comparison Group B) declines in mean blood-lead concentration nine months post-abatement. It was unclear exactly why the unabated residents experienced temporal variation in Phase I, though seasonal variation of a comparable magnitude has been identified previously in children's blood-lead levels (Kinateder and Menton, 1992; Schultz, 1993). This was a potential complicating factor in several of the efficacy studies. Also, the reductions reported for the control populations may have reflected the impact of age and behavioral factors stemming from an increased environmental awareness of the health hazard from lead.

4.0 CONCLUSIONS

This report assesses whether lead hazard intervention effectively improved the health of exposed children. Ideally, efficacy would be demonstrated in specific health outcomes among children benefitting from the intervention. However, only one such study was identified in the literature (Rosen et al., 1991; Markowitz et al., 1993; Ruff et al., 1993), and its interventions included chelation therapy. The lack of such studies is not surprising given the cost and difficulty associated with measuring health outcomes, especially among asymptomatic children with low to moderate lead exposure. Blood-lead concentration can serve as a surrogate health endpoint due to the recognized association between elevated blood-lead levels and adverse health effects. Such measures may not demonstrate the complete benefit of the intervention received by the child, but do illustrate its successful impact. In addition, their quantitative character allows for comparisons of different intervention strategies.

There is evidence within the literature that intervention did reduce exposed children's blood-lead concentrations (Table 4-1). Declines on the order of 18-34% were measured in exposed children's blood-lead levels six to 12 months following a variety of intervention strategies (Figure 4-1). Declines were reported for extensive, carefully managed projects which abated or isolated sources of lead, as well as routine cleaning procedures or educational instructions employed to alleviate the lead exposure of children. It should be noted, however, that short-term elevations in exposed children's blood-lead concentrations can result when abatements are performed improperly. Moreover, the evidence for post-intervention blood-lead concentration declines among children with pre-intervention levels less than 20 μg/dL is mixed.

Given the documented declines in blood-lead concentration, it is reasonable to investigate the degree to which they represent the actual effect of the intervention (e.g., that decline beyond changes due to unrelated factors). Four of the 16 identified studies also simultaneously traced changes in blood-lead level among a population of children not receiving the studied intervention strategy. The effect of their intervention may then be estimated as the difference in the decline recorded for the study population and that for the control population (Figure 4.2). The Milwaukee Retrospective Educational Study (Schultz, 1995) results indicate a 13.6% decline 2 to 15 months following intervention as the effect of their in-home educational outreach efforts. Dust control measures, conducted in the Baltimore Dust Control Study (Charney et al., 1983), were associated with a 16.1% effect 12 months following initiation. Soil abatements, performed in the Boston 3-City Soil Abatement Study (Weitzman et al., 1993; Aschengrau et al., 1994), exhibited an 11.5% effect by 11 months post-intervention. Finally, the 1990 St. Louis Paint Abatement Study (Staes et al., 1993) also reported an 11.5% effect on the blood-lead levels of resident children 10 to 14 months following the abatement of damaged lead-based paint (recall that a multiple linear regression model predicted a 13% effect). Though the data are limited, these results suggest that these intervention strategies are comparable in their effect on blood-lead concentrations.

Table 4-1. Summary of Intervention Efficacy for Identified Lead Hazard Intervention Studies

Study	Effective in Reducing Targeted Pathway of Exposure?	Effective in Reducing Exposed Child's Body-Lead Burden?
Baltimore Dust Control	Yes	Yes
1982 St. Louis Retrospective	nc	Yes
Baltimore "Traditional"/"Modified"	No	No*
Boston Retrospective	nc	Yes
Baltimore "Experimental"	Yes	na[1]
Central Massachusetts Retrospective	nc	Yes
Seattle Track-In	Yes	nc
1990 St. Louis Retrospective	nc	Yes
Boston 3-City	Yes	Yes
HUD Abatement Demonstration	Yes	na[1]
Comprehensive Abatement Performance	Yes	na[1]
Milwaukee Retrospective LBP	nc	Yes
New York Chelation	nc	Yes
Milwaukee Retro. Educational	na[2]	Yes
Granite City Educational	na[2]	Yes
Milwaukee Pro. Educational	na[2]	Yes

nc - Measurements necessary to make an assessment of the intervention's effectiveness were not collected.

* Modified abatement practices were associated with fewer increases in children's blood-lead concentrations.

na[1] Not applicable — Interventions performed on vacant housing.

na[2] Not applicable — Educational interventions were utilized in this study; no environmental interventions were performed.

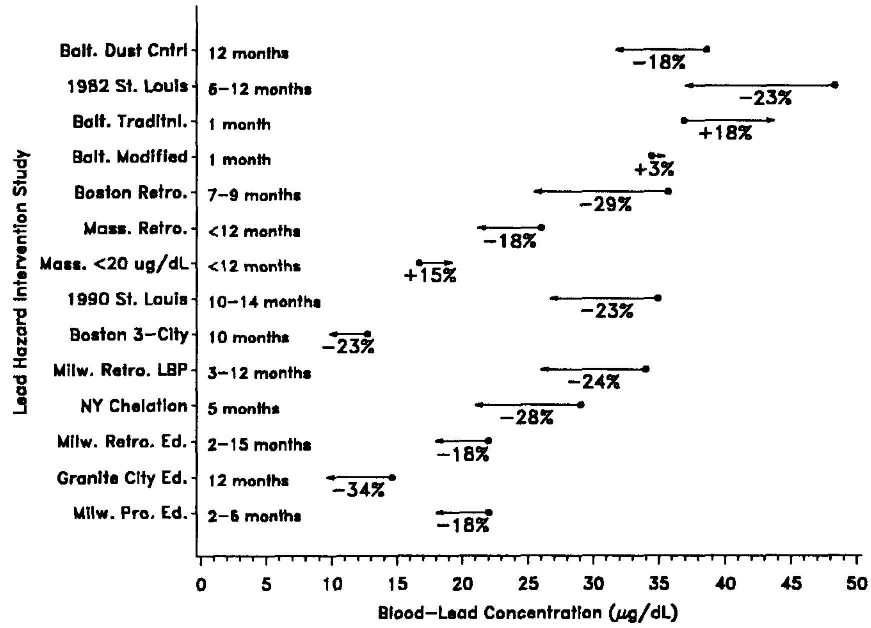

Figure 4-1. **Summary of blood-lead concentration results for identified lead hazard intervention studies.**

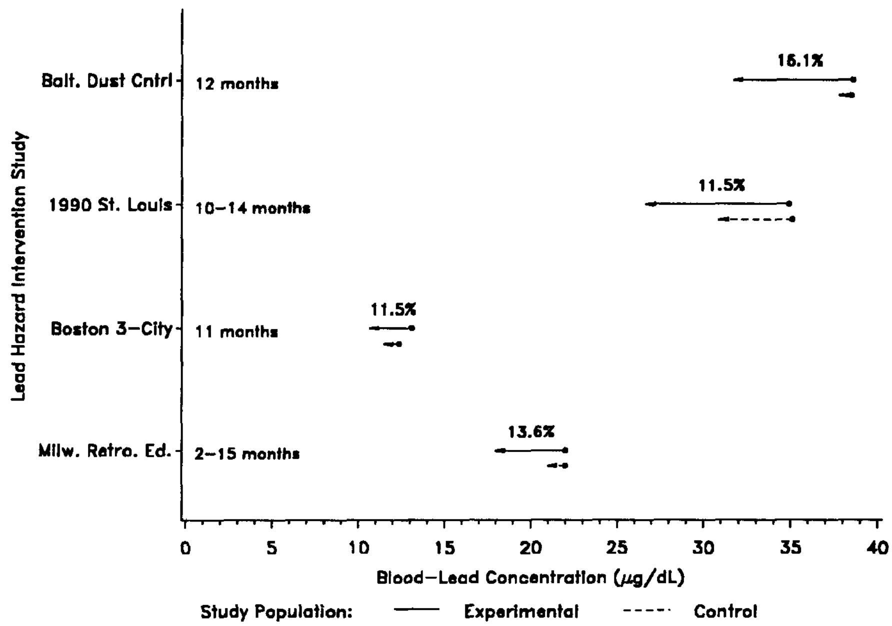

Figure 4-2. **Effect of lead hazard intervention as measured by declines in children's blood-lead concentration.**

The magnitude of the cited declines in blood-lead concentration are a function of a number of factors. Issues of source apportionment may limit observed blood lead reductions. Unless the micro-environments and lead hazards targeted by the intervention represent the full range of exposures, the intervention can only be partially successful. The timing of the measurements (relative to the intervention itself) and the kinetics of lead within the body, in turn, can impact the measured decline in body-lead burden. Mobilization of bone-lead stores following an intervention is capable of partially masking the effectiveness of the intervention. The length of time the masking can be maintained depends upon the degree of masking and the true effectiveness of the intervention. The analysis reported in Section 2.3 suggests that the observed 25% reductions in blood-lead level one year following the intervention are not the result of bone-lead mobilizations masking a fully effective intervention. In fact, it is unlikely that the interventions reduced the children's lead exposure by more than 50%.

Evolution in the techniques and guidelines associated with lead hazard abatement make comparison of the efficacy of different practices difficult. The literature does cite, however, beneficial results from the abatement of lead-based paint, elevated dust-lead levels, and elevated soil-lead levels. Moreover, declines in blood-lead levels after in-home educational efforts were observed in the same range as the other interventions, at least up to one year following intervention. The successful lead-based paint abatements described included removal methods, as well as encapsulation and enclosure methods. In contrast, dry scraping without HEPA vacuum attachments and open-flame burning of lead-based paint were both reported to produce considerable elevations in the lead burden of exposed children. It is still unclear whether more costly, large-scale abatement strategies are more successful than less expensive (though sometimes more labor intensive), in-place maintenance practices.

This dilemma emphasizes the limitations in the data currently available regarding the effectiveness of lead hazard intervention. Some studies are currently under way to further examine the efficacy of lead hazard interventions, including in-place management methods. The EPA is conducting the Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore to compare comprehensive and low-cost methods for lead-based paint abatement in terms of their efficacy for reducing the levels of lead in residential house dust and children's blood. The EPA is completing a study in Jersey City of strategies requiring lower up-front abatement costs. The 10 first-year recipients of HUD Abatement Grants will also soon provide information on currently implemented abatement practices. In a joint effort, the Centers for Disease Control and the EPA are sponsoring low-cost lead-based paint abatement evaluations in Baltimore, Cleveland, and Boston. In addition, results of the EPA 3-City Soil Abatement Demonstration Projects in Cincinnati and Baltimore should be released soon. So too should the results of an educational intervention in Leadville. Also, the National Institute of Environmental Health Sciences (NIEHS) is currently sponsoring a clinical drug trial to determine whether treatment with the drug succimer provides any additional benefit beyond environmental intervention. The trial is being conducted in four cities and examines children with moderately elevated (20-44 μg/dL) blood-lead concentrations. The results of these studies will shed additional light on the effectiveness of lead hazard intervention and the trade-offs between different in-place management and source isolation or removal strategies.

5.0 RECOMMENDATIONS FOR FUTURE INTERVENTION STUDIES

A critical question in planning studies to assess intervention effectiveness is the timing of the measurements following the interventions. Pre-intervention measures should be collected to provide a basis for comparison, but when should post-intervention measures be scheduled to best assess the effectiveness of an intervention? Frequent measurement collection is difficult and costly, especially for measures of health outcomes or body-lead burden. This issue is particularly pertinent when measuring a child's blood-lead concentration.

One timepoint is straightforward, one year post-intervention. The one-year timepoint minimizes the effect of seasonal variation (when compared to pre-intervention measurements), but does allow time for the effects of the intervention to become more fully manifest. The literature on bone-lead mobilization and the analysis detailed in Section 2.3 suggest that bone-lead stores mobilize over many months rather than days. Furthermore, one-year post-intervention measures should identify the effects of any recontamination of environmental media, and assess more fully the efficacy of intervention strategies which do not fully interdict a pathway of lead exposure. Bone-lead stores do have the potential for maintaining blood-lead concentrations above levels consistent with post-intervention exposure for more than one year. However, fully effective interventions should manifest much of their efficacy by the one year milestone.

It is also valuable to assess the progress of an intervention strategy by measuring its effectiveness before one year. The most suitable timing of such a measure, however, depends upon the age of the children targeted by the intervention, and the expected effectiveness of the intervention. Both seasonal variation and bone-lead mobilization may potentially impact a measured blood-lead concentration. Seasonal variation also impacts environmental lead measures. Table 5-1 presents some of the advantages and disadvantages to measuring intervention efficacy at 1, 3, and 6 months following the intervention. The bone-lead mobilization results presented in Table 2-5 are used to determine which children may be assessed post-intervention without detrimental confounding of the results due to mobilization of bone-lead stores.

Just as the timing of post-intervention measures is important, so too is the population of children to be examined. As is apparent in Section 3.0, the majority of identified studies examined children with considerably elevated blood-lead levels. These levels appear particularly elevated given the current 10 μg/dL level of concern cited by the CDC and the EPA. These studies provide valuable information on the potential benefit of lead hazard intervention, but do not address a significant portion of lead exposed children today. There is particular lack of information on the effectiveness of lead hazard intervention among moderately exposed children, specifically children with blood-lead concentrations at or below 20 μg/dL. Studies of such populations have occurred (Weitzman et al., 1993; Markowitz et al, 1993; Ruff et al., 1993; Kimbrough et al., 1994), but their results are mixed or not entirely relevant when considering non-medical interventions. The additional on-going research described in Section 4.0 should help in this regard, but other work may be appropriate. Absent too is information on effectiveness at time periods beyond one year, and more importantly, on the efficacy achieved by preventing elevated blood-lead concentrations before they occur (primary prevention). Measuring abatement effectiveness for moderately exposed children is particularly difficult, but the results are necessary in order to determine the role intervention should play in reducing childhood lead poisoning for this large population of children.

Table 5-1. Selection of Early Timepoint for Measuring Intervention Effectiveness

Timepoint Post-Intervention	Advantages	Disadvantages
1 month	• minimizes seasonal variation in blood-lead and environmental-lead levels • allows observation of transient elevations in blood-lead levels due to poorly performed interventions • provides baseline for assessment of recontamination of environmental media	• allows masking due to bone-lead mobilization for all children, regardless of the effectiveness of the intervention
3 months	• minimizes masking due to bone-lead mobilization for children 2 years or younger experiencing highly effective interventions	• allows masking due to bone-lead mobilization for children 3 years or older, and for younger children experiencing partially effective interventions • allows seasonal variation in blood-lead and environmental-lead levels, particularly at the summer/fall transition • provides no baseline for assessment of recontamination of environmental media • provides no information on transient elevations in blood-lead levels due to poorly performed interventions
6 months	• minimizes masking due to bone-lead mobilization for children 2 years of age or younger experiencing any intervention, as well as children 4 years of age or younger experiencing highly effective interventions	• allows masking due to bone-lead mobilization for children 5 years or older, and for younger children experiencing partially effective interventions • allows considerable seasonal variation in blood-lead and environmental-lead levels • same recontamination and transient elevation disadvantages as noted for 3 months

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA 747-R-95-006	2.	3. Recipient's Accession No.
4. Title and Subtitle Review of Studies Addressing Lead Abatement Effectiveness			5 Report Date: July 1995 6.
7 Author(s) David A. Burgoon, Steven W. Rust, Nancy A. Niemuth, Brandon J. Wood			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201-2693			10. Project/Task/Work Unit No. G001017-03 11. Contract(C) or Grant(G) No. (C) 68-D2-0139 (G)
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency Office of Pollution Prevention and Toxics 401 M Street, S.W. Washington, D.C. 20460			13. Type of Report & Period Covered Final Report 14.

15. Supplementary Notes

16. Abstract (Limit 200 words)

This report is a comprehensive review of the scientific literature regarding the effectiveness of lead hazard intervention. One use of this review is to aid in assessing the potential benefits of Title X rule-making activities.

The literature is limited in its extent, and it only covers some of the intervention methods used in practice. However, the scientific literature does indicate that blood-lead concentrations declined after lead hazard intervention for children with blood-lead levels ≥ 20 μg/dL. Declines of 18-34% were measured in exposed children's blood-lead levels 6-12 months following a variety of intervention strategies. Also, evidence suggests that short-term elevations in exposed children's blood-lead concentrations may result when abatements are performed improperly.

Evolution in the techniques associated with abatement make comparison of the effectiveness of different practices difficult. There is insufficient information available to identify a particular intervention strategy as markedly more effective than another. The literature cites comparable reductions in blood-lead concentration resulting from the abatement of lead-based paint, dust at elevated lead levels, and soil at elevated lead levels. Moreover, declines in blood-lead levels after in-home educational efforts were observed in the same range as the other interventions.

17. Document Analysis

a. Descriptors

Lead Poisoning, Abatement, Effectiyeness, Reviews

b. Identifiers/Open-Ended Terms

Lead Hazard Intervention, Abatement Effectiveness, Literature Survey, Blood-Lead Concentration

c. COSATI Field/Group

18. Availability Statement Release Unlimited	19. Security Class (This Report) Unclassified	21. No. of Pages 144
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-239.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

APPENDIX A

ABSTRACTS OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS

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APPENDIX A

ABSTRACTS OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS

A.1 Baltimore Dust Control Study

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

Pertinent Study Objectives. This study sought to assess whether periodic dust-control measures in addition to lead-based paint abatement would be more effective in reducing blood-lead concentrations than lead-based paint abatement alone.

Sampled Population. Forty-nine children aged 15 to 72 months with at least two confirmed blood-lead concentrations between 30 and 49 μg/dL formed the study population. These children were divided into an experimental group of 14 children and a control group of 35 children. All the children were patients at the Lead Poisoning Clinic of the John F. Kennedy Institute in Baltimore, Maryland.

Intervention Strategy. Both the experimental and control group underwent lead-based paint abatement which entailed removing all peeling lead-containing interior and exterior paint from the residence. In addition, all child accessible surfaces (below 1.2 m) which may be chewed on were covered or rendered lead-free. For the experimental group only, periodic dust-control involved twice monthly visits by a dust-control team who wet-mopped all rooms in the residence where the dust-lead loading was greater than 100 μg/sq.ft.

Measurements Taken. Dust-lead loading measurements were collected from all areas within the residence where the child spent time. The samples were collected with alcohol-treated wipes within a 1 ft^2 area of floor or from the entire window sill. Blood-lead (PbB), free erythrocyte protoporphyrin (FEP), and hematocrit levels were measured during regular visits to the clinic.

Study Design and Results. Measurements of PbB, FEP and hematocrit were taken approximately every three months during the course of the study. For the experimental group, there was a significant reduction in mean PbB and FEP after six months, and a further decrease after one year (Tables A.1-1, A.1-2). In contrast, the mean value for the control group did not change significantly over the twelve months.

For many of the children, PbB levels six months prior to the study were available. Although the PbB levels for most children were stable prior to the study, a mean increase of 1.0 μg/dL was reported in each group, but these increases were not statistically significant. At the start of the study, PbB levels for 8 of 11 children in the experimental group and 15 of 24 children in the control group remained within 3 μg/dL of their respective levels six months before.

Residential dust-lead loadings were collected for the experimental group during recruitment. No dust-lead measurements were collected in the control residences so as to avoid drawing attention to dust as a source of lead exposure. To assess the success in cleaning, dust-lead loading measurements were also obtained before and after the dust-control teams completed their work.

Though the cleaning was effective, elevated levels returned in most homes within two weeks following cleaning. It took several months before all the study residences had persistent reductions in dust-lead levels. After 12 months, however, the cleaning was effective. Within experimental residences, the bimonthly dust-control efforts reduced the dust-lead loading on measured surfaces (Table A.1-3).

Table A.1-1. Blood-Lead Concentration (μg/dL) by Study Group and Time

Group	Time	N	Mean	Std. Error
Experiment	Start	14	38.6	5.2
	6 months	14	33.3	3.6
	12 months	14	31.7	2.6
Control	Start	35	38.5	5.2
	6 months	33	38.7	2.6
	12 months	35	37.8	7.9

Table A.1-2. Free Erythrocyte Protoporphyrin Concentration (μg/dL) by Study Group and Time

Group	Time	N	Mean	Std. Error
Experiment	Start	14	203	99
	6 months	14	158	76
	12 months	14	144	82
Control	Start	35	231	103
	6 months	33	216	125
	12 months	35	208	130

Table A.1-3. Number of Experimental Residences by Maximum Dust-Lead Loading and Time

Max. PbD (μg/ft^2)	Study Inception	After 12 months
$<$100	1	5
100-200	1	4
200-400	1	1
400-800	3	4
800-1600	4	0
$\geq$1600	4	0

Conclusions (including caveats). The lead loading of house dust may be reduced by regular and focused dust-control efforts within the residence, and the blood-lead levels in children residing in those homes can be significantly lowered. The children examined in this study were already lead-poisoned, so it is unclear how efficacious such procedures would be with children exhibiting lower blood-lead concentrations. The dust-lead loadings return rapidly to elevated levels if the cleaning procedures are discontinued.

A.2 1982 St. Louis Retrospective Paint Abatement Study

Reference. Copley, C. G. (1983) "The Effect of Lead Hazard Source Abatement and Clinic Appointment Compliance on the Mean Decrease of Blood Lead and Zinc Protoporphyrin Levels." Mimeo. City of St. Louis, Department of Health and Hospitals, Division of Health, Office of the Health Commissioner, St. Louis, MO.

Pertinent Study Objectives. This study sought to demonstrate a significant difference between the children living in abated environments after lead hazard intervention compared to children still exposed to lead hazards.

Sampled Population. The comparison was made among children enrolled in the St. Louis Health Division's Childhood Lead Poisoning Prevention Program and measured to have a blood-lead concentration greater than 25 μg/dL.

Intervention Strategy. The lead hazard intervention entailed the enclosure or removal of paint from surfaces with peeling or broken leaded paint. Chewable surfaces with evidence of damage were completely stripped. Extensive cleanup procedures were not required and were likely implemented infrequently at best. Replacement of building components in question (e.g., window sills, baseboards) was recommended, but used infrequently.

Measurements Taken. The blood-lead concentration measurements were collected during routine venipuncture screening. Lead containing paint was identified using XRF.

Study Design and Results. A retrospective study compared those blood measurements which identified the child as lead poisoned to follow-up samples collected six to twelve months following the initial identification. A total of 102 children had sufficient samples collected to allow this comparison. Follow-up blood-lead concentrations in children whose lead hazards had been abated were found to be significantly lower than their initial levels (Table A.2-1). This was not the case for children whose hazards had not yet been abated. Blood-lead concentrations fell significantly in children regardless of the extent to which their guardians successfully met their scheduled appointments. Similar results were seen for zinc protoporphyrin concentrations (Table A.2-2).

Table A.2-1. Blood-Lead Concentration (μg/dL) by Study Group

Study Group	Sample Size	Initial Sample Arith. Mean	Follow-up Sample Arith. Mean
All Children	102	46.13	38.87
Abated Homes	61	48.31	37.02
Unabated Homes	41	42.88	41.63
Compliance ≥50%	63	47.60	38.82
Compliance ≤50%	39	43.74	38.95

Table A.2-2. Zinc Protoporphyrin Concentration (μg/dL) by Study Group

Study Group	Sample Size	Initial Sample Arith. Mean	Follow-up Sample Arith. Mean
All Children	102	111.04	87.19
Abated Homes	61	119.43	81.56
Unabated Homes	41	98.56	95.56
Compliance $\geq$50%	63	126.10	96.06
Compliance $\leq$50%	39	86.72	72.85

Conclusions (including caveats). The results indicate that abatement of lead-based paint hazards does significantly reduce the lead burden being borne by lead-poisoned children. The magnitude of the reduction, however, is confounded with the timing of the sampling (seasonal variation may play a role) and the age of the children (PbB levels usually peak at 2 years of age).

A.3 Baltimore Traditional/Modified Paint Abatement Study

Reference. Farfel, M. R., and Chisolm, J. J. Jr. (1990) "Health and Environmental Outcomes of Traditional and Modified Practices or Abatement of Residential Lead-Based Paint." *American Journal of Public Health.* 80(10):1240-1245.

Pertinent Study Objectives. The goal of this study was to evaluate the health and environmental impact of traditional and modified practices for the abatement of lead-based paint.

Sampled Population. The study examined children residing in 71 residences abated in urban Baltimore (53 traditional abatements, 18 modified abatements). Prior to abatement all the residences had multiple interior surfaces coated with lead-based paint and housed at least one child with a blood-lead concentration greater than 30 μg/dL.

Intervention Strategy. Traditional abatement practices called for addressing deteriorated paint on surfaces up to four feet from the floor, and all hazardous paint on accessible surfaces which may be chewed on. Paint with a lead content greater than 0.7 mg/cm^2 by XRF or 0.5% by weight by wet chemical analysis was denoted hazardous. For traditional abatements, blow torches and/or dry sanding were commonly used, the abated surfaces were not repainted, and clean-up typically entailed, at most, dry sweeping. Modified practices excluded the use of open-flame burning and sanding techniques and included the repainting of abated surfaces. In addition, it called for more extensive clean-up efforts entailing wet-mopping with a high phosphate detergent, vacuuming with a standard shop vacuum, and disposal of debris off-site. In addition, worker training, protection, and supervision were provided.

Measurements Taken. Dust samples were obtained using a alcohol-treated wipe within a defined area template (1 ft^2). Blood samples were collected via venipuncture.

Study Design and Results. Serial measurements of lead in interior house dust-lead loading (PbD), and children's blood-lead concentration (PbB) were collected. Increased dust-lead loadings were measured immediately following traditional abatements (usually within two days) on or in close proximity to abated surfaces (Tables A.3-1, A.3-2, and A.3-3). Dust-lead levels measured after modified abatements were also higher than pre-abatement levels, but not to the extent seen for traditional practices. At six months post-abatement, PbD levels were comparable to, or greater than, their respective pre-abatement loadings in both study groups. It should be noted that neither traditional nor modified practices entailed the abatement of window wells within the residence.

Table A.3-1. Floor Dust-Lead Loading ($\mu g/ft^2$) by Group and Time*

Time Period	Study Group	Sample Size	Geometric Mean	95% Conf. Interval
Pre-Abatement	Traditional	280	251	(223, 288)
	Modified	82	288	(204, 390)
Post-Abatement	Traditional	271	1440	(1198, 1719)
	Modified	50	650	(455, 920)
6 Months Post-Abatement	Traditional	234	316	(269, 362)
	Modified	57	316	(242, 418)

Table A.3-2. Window Sill Dust-Lead Loading ($\mu g/ft^2$) by Group and Time*

Time Period	Study Group	Sample Size	Geometric Mean	95% Conf. Interval
Pre-Abatement	Traditional	249	1338	(1096, 1616)
	Modified	45	1802	(1356, 2406)
Post-Abatement	Traditional	246	3595	(2889, 4459)
	Modified	64	604	(446, 818)
6 Months Post-Abatement	Traditional	199	1542	(1226, 1942)
	Modified	66	1635	(1152, 2323)

Table A.3-3. Window Well Dust-Lead Loading ($\mu g/ft^2$) by Group and Time*

Time Period	Study Group	Sample Size	Geometric Mean	95% Conf. Interval
Pre-Abatement	Traditional	150	15496	(11585, 20745)
	Modified	37	18274	(11316, 29515)
Post-Abatement	Traditional	139	14354	(11223, 18348)
	Modified	24	8083	(4887, 13369)
6 Months Post-Abatement	Traditional	100	12468	(9012, 17243)
	Modified	32	24879	(15301, 40450)

* Dust-lead loading results were converted from mg Pb per m^2 to μg Pb per ft^2.

In order to assess blood-lead concentration, an additional 25 modified practices abated residences were considered. No dust samples were collected in these residences. All the residences under consideration housed a total of 151 children eligible for PbB analysis. Seventy-eight of these children had sufficient follow-up venous samples to allow their consideration in at least one component of the analysis. Forty-six children who did not undergo any chelation therapy had pre- and post-abatement samples. The post-abatement samples were collected within one month following the completion of the abatement activities. In residences abated using either practice, PbB levels in resident children rose significantly (Table A.3-4). At six months following abatement, 29 children with no history of chelation therapy (14 residing in traditionally abated dwellings, 15 in modified) continued to suffer from elevated PbB levels (arithmetic mean: 32.53 μg/dL) which were not significantly different from their pre-abatement measures (arithmetic mean, 30.67 μg/dL).

Table A.3-4. Blood-Lead Concentration (μg/dL) by Group and Time*

Study Group	Sample Size	Pre-Abatement		One Month Post-Abatement	
		Arith. Mean	Std. Error	Arith. Mean	Std. Error
Traditional	27	36.88	1.45	43.72	2.69
Modified	19	34.40	2.07	35.43	2.49

* Blood lead concentrations were converted from μmol/L to μg/dL by multiplying by 20.72.

Conclusions (including caveats). Despite the implementation of improved practices, modified abatements, like traditional abatements, did not result in any long-term reductions of levels of lead in house dust or the blood of children with elevated pre-abatement PbB levels. In addition, the activities further elevated blood-lead concentrations.

A.4 Boston Retrospective Paint Abatement Study

Reference. Amitai, Y., Brown, M. J., Graef, J. W., Cosgrove, E. (1991) "Residential Deleading: Effects on the Blood Lead Levels of Lead-Poisoned Children." *Pediatrics.* 88(5):893-897.

Pertinent Study Objectives. This study sought to evaluate the extent to which the lead poisoning of children is exacerbated during the abatement of lead-based paint within their residence.

Sampled Population. The study population consisted of 114 children ranging in age from 11 to 72 months (median: 24 months) with at least one blood-lead concentration above 25 μg/dL obtained prior to deleading, one blood-lead sample collected during deleading, and one blood-lead determination following the completion of the deleading process. All the children were enrolled in the Massachusetts Department of Public Health's Childhood Lead Poisoning Prevention Program.

Intervention Strategy. The deleading process consisted of the removal or permanent coverage of any paint with a lead content greater than 1.2 mg/cm^2 which was loose and peeling, or present on chewable surfaces accessible to the child (below 4 ft). Abatement was accomplished using an unspecified combination of methods including dry scraping and sanding, blow torch burning, and replacement or permanent enclosure of building components. Detailed cleanup practices (i.e., HEPA vacuuming and TSP washing) and relocation of the occupants during the abatements were recommended, but not uniformly followed.

Measurements Taken. The blood-lead concentration measurements were collected via venipuncture.

Study Design and Results. The geometric mean PbB in the 114 children rose during deleading and fell following the completion of the deleading activities (Table A.4-1). Post-deleading measures were determined an average of 49±8 days (mean±standard error) after the deleading activities were completed. The mid-deleading measures were obtained 63±4 days following the pre-deleading samples. The decrease in geometric mean PbB post-deleading is due in part to 42 children who underwent chelation therapy between the mid- and post-deleading measurements.

Table A.4-1. Blood-Lead Concentration (μg/dL) by Time

Time Period	Geometric Mean	Standard Error
pre-deleading	36.4	0.6
mid-deleading	42.1	1.5
post-deleading	33.5	1.0

In an effort to determine the effect of deleading activities alone, a subset of 59 children who underwent no chelation therapy were examined. In this subset, an additional follow-up measure was collected 250±14 days after completion of the deleading work. No evidence of a change in geometric mean PbB was found, but blood-lead levels did fall at the post-deleading collection and fell even further by the follow-up deleading collection (Table A.4-2).

Table A.4-2. Blood-Lead Concentration (μg/dL) by Time

Time	Geometric Mean	Standard Error
pre-deleading	35.7	0.9
mid-deleading	35.5	0.8
post-deleading	31.0	1.0
follow-up	25.5	0.9

For 80 of the children, the specific method of deleading was available. Dry scraping and torches considerably elevated the blood-lead levels of the affected children (Table A.4-3). By comparison, children exposed to encapsulation, enclosure, or replacement abatement procedures experienced a mean decrease in their blood-lead burden. The stability of PbB prior to deleading activities was characterized for a subset of 32 children who had two blood samples prior to deleading. The mean PbB rose from 35.4 ± 1.3 μg/dL to 36.0 ± 1.1 μg/dL during the interval between these samples (73 ± 23 days).

Table A.4-3. Change in Mid-Deleading PbB (μg/dL) by Method of Abatement

Method	# of Homes	Arith. Mean	Std. Error
dry scraping and sanding	41	+9.1	2.4
encap, enclose, or replace	12	-2.25	2.4
torches employed	9	+35.7	10.8

Conclusions (including caveats). Deleading may often produce a significant, transient elevation of PbB in many children. It is most dangerous if accomplished with the use of torches, sanding, or dry scraping. The results for non-chelated children should be viewed with caution, since their long-term reductions may be due to reasons other than paint abatement. Perhaps the children were not chelated because their levels were falling naturally.

A.5 Baltimore Experimental Paint Abatement Study

Reference. Farfel, M. R. and Chisolm, J. J. Jr. (1991) "An Evaluation of Experimental Practices for Abatement of Residential Lead-Based Paint: Report on a Pilot Project." *Environmental Research.* 55:199-212.

Farfel, M. R., Chisolm, J. J. Jr., and Rohde, C. A. (1994) "The Longer-Term Effectiveness of Residential Lead Paint - Abatement." *Environmental Research.* 66:217-221.

Pertinent Study Objectives. The study sought to demonstrate and evaluate experimental lead-based paint abatement practices developed in response to the inadequacies uncovered for traditional abatement procedures (see A.3).

Sampled Population. The literature on this study examined two distinct subsets of dwellings in urban Baltimore. The first set is composed of six older dwellings in Baltimore City which were built in the 1920s. Each dwelling was a two-story six-room row home in poorly maintained condition with multiple lead-based paint hazards. Four of the residences were vacant, two housed lead-poisoned children. The second set consisted of 13 dwellings which had previously been abated between 1988 and 1991 according to Maryland regulations. Each dwelling had 1) at least six pairs of dust-lead loading (PbD) measures taken from the same locations pre- and immediately post-abatement; 2) no major renovations performed since abatement; and 3) occupancy by a family providing written informed consent.

Intervention Strategy. The experimental practices called for the floor to ceiling abatement of all interior and exterior surfaces where lead content of the paint exceeded 0.7 mg/cm^2 by XRF or 0.5% by weight by wet chemical analysis. Several methods were tested, including encapsulation, off-site and on-site stripping and replacement. The abatements took place either in unoccupied dwellings or the occupants were relocated during the abatement process. Lead-contaminated dust was contained and minimized during the abatement, and extensive clean-up activities included HEPA vacuuming and off-site waste disposal. In addition, extensive worker training and protection were provided.

Measurements Taken. Alcohol-treated wet wipes were used to collect dust-lead loading samples from household surfaces within each residence. Soil samples were taken with a 15.24 cm stainless steel probe.

Study Design and Results. This abstract considers the reported results for the two nonoverlapping subsets of this study. The first set of analyses (Farfel et al., 1991) examined serial measurements of lead in interior dust samples in six homes. Dust samples were collected immediately before initiating abatement (pre-abatement), during the abatement, after the final clean-up (post-abatement), and one, three, and six to nine months following the abatement. Dust-lead loadings immediately post-abatement were significantly lower than pre-abatement levels (Tables A.5-1 through A.5-3). By six to nine months following the abatements, these levels either improved further or remained unchanged.

PbD monitoring before, during, and after the abatement activities also provided information on the effectiveness of particular measures. All floor and window treatments were associated with significant decreases in PbD over time (Tables A.5-4a,b). Window replacement was reported to be more effective in reducing dust lead loading than stripping the lead-based paint. In addition, vinyl floor coverings produced lower dust-lead loadings than sealing old wooden floors with polyurethane.

Table A.5-1. Floor Dust-Lead Loading ($\mu g/ft^2$) in Six Homes by Time Period*

Time Period	Sample Size	Geometric Mean	95% Conf. Int.
Pre-abatement	70	520	(390, 697)
Post-abatement	70	130	(102, 176)
6 Months Post	63	56	(46, 74)

Table A.5-2. Window Sill Dust-Lead Loading ($\mu g/ft^2$) in Six Homes by Time Period*

Time Period	Sample Size	Geometric Mean	95% Conf. Int.
Pre-abatement	34	4608	(3019, 7024)
Post-abatement	35	325	(195, 557)
6 Months Post	31	409	(242, 669)

Table A.5-3. Window Well Dust-Lead Loading ($\mu g/ft^2$) in Six Homes by Time Period*

Time Period	Sample Size	Geometric Mean	95% Conf. Int.
Pre-abatement	28	29422	(18060, 47938)
Post-abatement	31	938	(567, 1561)
6 Months Post	24	1003	(548, 1849)

* Dust-lead loading results were converted from mg Pb per m^2 to μg Pb per ft^2.

The second set of analyses (Farfel et al., 1994) examined wipe-dust samples (n=179) collected from thirteen study dwellings between December 1991 and January 1992. These measures were made prior to abatement, immediately post-abatement, and 1.5 to 3.5 years post-abatement. Dust-lead loadings 1.5 to 3.5 years post-abatement were significatly lower from pre- and immediately post-abatement levels (Table A.5-5). Soil-lead concentration which ranged from 209 to 1962 $\mu g/g$ (GM=688 $\mu g/g$, Log SD=0.69) was not found to be a significant factor in explaining the change in dust-lead levels. 1.5 to 3.5 years following intervention 78% of all dust lead loading measurements were within Maryland's interim post-abatement clearance standards (200 $\mu g/ft^2$ for floors, 500 $\mu g/ft^2$ for window sills, and 800 $\mu g/ft^2$ for window wells). Twenty-one of the 39 readings above the clearance levels were from window wells. Ratios of dust-lead loadings at 1.5 to 3.5 years post-abatement to those pre- and immediately post-abatement were calculated (Table A.5-6). Despite some reaccumulation of lead in dust, geometric mean PbD levels 1.5 to 3.5 years post-abatement were significantly less than pre-abatement levels.

Table A.5-4a. Geometric Mean PbD Loadings ($\mu g/ft^2$) in Six Homes by Type of Surface and Treatment*

Surface and Treatment	Pre-Abatement		Post-Abatement		Post-Treatment		Post Clean-up	
	N	G. Mean	N	G. Mean	N	G. Mean	N	G. Mean
Floors								
Urethane	58	492	58	2313	56	28	58	139
Vinyl tile	12	688	12	3391	12	622	12	102
Window Sills								
On-site caustic strip	26	4069	27	10043	24	1133	27	316
Off-site caustic strip	8	6912	-		7	1115	8	372
Window Wells								
New Window	11	15580	13	2230	13	1208	14	502
On-Site caustic strip	17	44361	16	29376	12	5639	17	1589

Table A.5-4b. Geometric Mean PbD Loadings ($\mu g/ft^2$) in Six Homes by Type of Surface and Treatment*

Surface and Treatment	1 Month Post		3 Months Post		6-9 Months Post	
	N	G. Mean	N	G. Mean	N	G. Mean
Floors						
Urethane	43	102	54	93	51	74
Vinyl tile	10	46	12	37	12	19
Window Sills						
On-site caustic strip	24	418	25	539	23	353
Off-site caustic strip	6	1143	8	483	8	604
Window Wells						
New Window	10	251	13	474	14	465
On-Site caustic strip	15	5314	15	7107	10	2945

* Dust-lead loading results were converted from mg Pb per m^2 to μg Pb per ft^2.

Table A.5-5. Geometric Mean PbD Loadings ($\mu g/ft^2$) in Thirteen Homes by Surface Type*

Surface Type	Pre-abatement PbD		Post-abatement PbD		1.5 to 3.5 Years Post-abatement	
	N	G. Mean (95% CI)	N	G. Mean (95% CI)	N	G. Mean (95% CI)
Floor	42	254 (143,452)	47	13.9 (7.4,25.1)	71	40.9 (25.1,68.8)
Window Sill	53	1041 (542,2007)	54	13.0 (7.4,22.3)	59	103 (66,161)
Window Well	31	14214 (7339,27778)	41	34.4 (22.3,53.0)	49	600 (345,1041)

Table A.5-6. Ratios of 1.5 to 3.5 Year Dust-Lead Loadings (PbD) to Those Pre- and Post-abatement for Thirteen Homes.

Surface Type	1.5 to 3.5 Years / Pre-abatement (95% CI)	1.5 to 3.5 Years / Immediate Post-abatement (95% CI)
Floor	0.16 (0.09,0.31)	2.9 (1.5, 6.3)
Window Sill	0.10 (0.05, 0.20)	7.9 (4.4, 15)
Window Well	0.04 (0.02, 0.08)	17 (9.1,31)

* Dust-lead loading results were converted from mg Pb per m^2 to μg Pb per ft^2.

Conclusions (including caveats). The experimental methods resulted in substantial reductions in interior surface dust-lead levels immediately post-abatement which were found to persist throughout a 6- to 9-month post-abatement period. By the 1.5 to 3.5 year post-abatement measures, 78% of the readings remained below target levels ($< 140\ \mu g/ft^2$). Dust-lead concentrations at this time were reduced to 16, 10, and 4% of pre-abatement levels for floors, window sills, and window wells, respectively. This suggests that comprehensive lead-paint abatement is associated with short-term as well as the longer-term control of residential dust-lead hazards. Reaccumulation of dust was greatest for window wells. The magnitude of the decline in dust-lead loadings following abatement may have been exaggerated for the first subset since vacant units are likely to contain more dust than occupied units.

A.6 Central Massachusetts Retrospective Paint Abatement Study

Reference. Swindell, S. L., Charney, E., Brown, M. J., Delaney, J. (1994) "Home Abatement and Blood Lead Changes in Children With Class III Lead Poisoning." *Clinical Pediatrics*. September:536-541.

Charney, E., Personal Communication, February, 1995.

Pertinent Study Objectives. This retrospective study was designed to assess the effect of residential lead-based paint abatements practiced between 1987 and 1990 in central Massachusetts. More stringent home deleading regulations were enacted in Massachusetts in 1988 during the conduct of the study.

Sampled Population. The sample population consisted of 132 children ranging in age from 12 to 91 months (mean: 35 months) who were identified by the Massachusetts Department of Public Health as having a blood-lead concentration (PbB) ≥ 25 μg/dL between 1987 and 1990, and whose homes were abated during this period. Moreover, the child must have had at least one venous PbB determination within 6 months prior to abatement; at least one venous PbB detemination 2 weeks to 6 months following abatement; must not have received chelation therapy during that time period; and must have resided in the same dwelling throughout the study period.

Intervention Strategy. Interventions prior to 1988 consisted of the removal or permanent coverage of any paint with a lead content greater than 1.2 mg/cm^2 which was loose or peeling, or present on chewable surfaces accessible to the child (below 4 ft). No standard abatement methods, dust-control measures or cleanup procedures were mandated. After 1988, only hand-scraping and replacement of parts were acceptable removal methods and all occupants were removed from the dwelling during the entire deleading and cleaning process. Cleanup involved vacuuming all surfaces with a high-efficiency particle air (HEPA) filter vacuum, followed by wet-mopping and sponging with a trisodium phosphate cleaning solution and then a second HEPA vacuuming. Abatement contractors were licensed, which required completion of a 3-day course and passing a certifying exam.

Measurements Taken. Blood-lead concentration measurements were collected via venipuncture.

Study Design and Results. Childrens' blood-lead concentration measures at most 6 months prior to initiation of abatement were compared to the last measurement collected within one year following abatement. The actual range of post-abatement measures was 3 to 52 weeks following abatement. Although a venous PbB level of ≥ 25 μg/dL was chosen as a criterion for this retrospective study, blood-lead concentration immediately prior to the abatement were less than 25 μg/dL for some children. In these cases, the authors suggest that the pre-abatement PbB measure might have reflected some early abatement or education effects. Of the total 132 children, 103 (78%) showed a reduction in PbB within one year following intervention. Table A.6-1 presents the number of children whose blood-lead levels increased or decreased between pre- and post-abatement measures. However, this reduction varied with pre-abatement level (Table A.6-2). In fact, mean blood-lead levels for subjects with initial PbB ≥ 20 μg/dL decreased, while mean blood-lead concentrations for subjects with pre-abatement PbB < 20 μg/dL increased from 16.7 to 19.2 μg/dL.

Table A.6-1. Number of Children Whose PbB Changed Between Pre- and Post-abatement Measurements by Amount of Change

Change in PbB Between Pre- and Post-abatement levels (μg/dL)		Number of Children
Decrease	>12	12
	9-12	20
	5-8	31
	1-4	40
No Change	0	4
Increase	1-4	9
	5-8	5
	9-12	5
	>12	6

Table A.6-2. Blood-Lead Concentration (μg/dL) by Pre-abatement Level

Pre-abatement PbB Level	Sample Size	# (%) in Sample with Decreased Post-abatement PbB	Mean PbB Level		Mean Change in PbB Level (%)
			Pre-abatement	Post-abatement	
Complete Sample	132	103 (78%)	26.0	21.2	-4.8 (-18%)
≥ 30	33	32 (97%)	34.2	23.2	-11.0 (-32%)
20 - 29	79	64 (81%)	24.9	20.8	-4.1 (-16%)
< 20	20	7 (35%)	16.7	19.2	+2.5 (+15%)

There were no significant differences in the reduction of blood-lead concentration between males and females, nor were there indications of differences among age groups. However, all age groups showed significant decreases post-abatement. Despite the more stringent regulations beginning in 1988, reduction in PbB levels by calendar year of abatement were not found to be meaningful (Table A.6-3). The increase of 0.1 μg/dL in 1990 was significantly different from the decreases observed in the three previous years. This increase was accounted for by a small sample size (n=13) and the presence of two children whose levels increased markedly (from 16.0 and 17.0 μg/dL to 29.0 and 31.0 μg/dL). The median change from pre- to post-abatement measures was a decrease of 2.0 μg/dL in that year, while the mean PbB remained relatively unchanged when the two children were excluded.

Among 72 children with more than one pre-abatement measure, 40 children whose levels were declining (defined as a decrease greater than 5 μg/dL) prior to abatement exhibited only a modest

Table A.6-3. Blood-Lead Concentration (μg/dL) Change by Year

Year	Sample Size	Mean PbB Level		Mean Change in PbB	
		Pre-abatement	Post-abatement	Absolute	Percent
1987	29	27.5	22.2	-5.3	-19%
1988	48	26.1	20.4	-5.7	-21%
1989	42	24.3	19.6	-4.7	-19%
1990	13	23.9	24.0	+0.1	+0.4%

Table A.6-4. Blood-Lead Concentration (μg/dL) by Timing of Post-Abatement Measure

# of Days Post-abatement	Sample Size	Mean PbB Level		Mean Change in PbB
		Pre-abatement	Post-abatement	
14-90	29	24.2	21.2	-3.0
91-180	47	25.3	20.0	-5.3
181-270	31	27.5	23.4	-4.1
271-365	25	25.8	19.4	-6.4

further mean decline of 1.9 μg/dL. A more significant mean decline of 8.2 μg/dL was observed for the 32 children whose initial levels were relatively constant.

Seasonal variations in blood-lead concentrations may be a factor in confounding the declines, especially since post-abatement measures were taken from 3 to 52 weeks after the abatement process (Table A.6-4). But all mean blood-lead concentrations decreased by their post-abatement measure indifferent of timing.

Conclusions (including caveats). These results demonstrate that abatement of lead-contaminated paint in residential homes is associated with a modest decline in blood-lead levels. The significant decline among 32 children with stable levels prior to abatement suggests that regression to the mean cannot fully account for the observed decline. Moreover, the magnitude of the decline appears to depend upon the child's initial PbB. For children with blood-lead levels $\geq$25 μg/dL, and particularly above 30 μg/dL, lead-based paint abatement as practiced between 1987 and 1990 was associated with an approximate 18% mean decline in blood-lead concentrations. The decline was not as significant in children whose pre-abatement PbB levels were less than 25 μg/dL, and particularly below 20 μg/dL. The decline may be confounded by the quality of the abatement process itself. Although more stringent regulations were enacted in 1988, the prescribed methods may not have been used immediately. Also, seasonal and age variation in blood-lead concentrations could significantly impact the observed decline, depending upon the period of time between the measures and the season in which the measures were collected.

A.7 Seattle Track-In Study

Reference. Roberts, J. W., Camann, D. E., Spittler, T. M. (1991) "Reducing Lead Exposure from Remodeling and Soil Track-In in Older Homes." Presented at the 84th Annual Meeting of the Air and Waste Management Association. June 16-21, 1991.

Pertinent Study Objectives. The study sought to determine the extent to which low cost dust-control measures successfully lower household dust-lead loading (PbD).

Sampled Population. Forty-two homes in Seattle and Port Townsend, Washington built before 1950 formed the sample populations.

Intervention Strategy. The abatement procedures considered between 1988 and 1990 were strictly low-cost dust reduction procedures: use of a vacuum cleaner with an agitator bar, removing shoes at the entrance to the residence, and installation of walk-off mats.

Measurements Taken. Dust samples were collected from rugs within the residence using a Hoover Convertible vacuum cleaner. Soil samples were scraped from within one foot of the residence's foundation. Total dust-lead loadings and fine dust-lead loadings (seived before analysis) were measured.

Study Design and Results. The study employed piece-wise regression analysis to assess which factors determine the dust-lead loading within a residence. Significant pairwise correlations were found between ln(PbD) and removing shoes at the door ($r=-0.62$) and the presence of a walk-off mat at the home's entrance ($r=-0.48$). Lower dust-lead levels were found in homes where the residents removed their shoes and/or utilized a walk-off mat (Table A.7-1).

Table A.7-1. Dust Levels within Residences by Abatement Procedure

Measure	Shoes Off	Shoes On	Walk-off Mat
Number of Homes	5	32	6
Total Dust Loading (mg/ft^2)*	325.2	2415.5	622.5
Fine Dust Loading (mg/ft^2)*	74.3	929	157.9
Fine Dust-Lead Loading (μg/ft^2)*	28.8	994.1	53.9
Fine Dust-Lead Concentration (ppm)	320	780	430

* Loadings converted from amount Pb per m^2 to per ft^2.

The occupants of three homes tested in the study began removing their shoes upon entry for at least five months prior to the collection of a second PbD measurement from their carpets. In addition, the occupants of one of these homes installed walk-off mats at both entrances and began vacuuming twice weekly. The geometric mean dust-lead loading fell from 1588.6 μg/ft^2 to 23.2 μg/ft^2 in these homes.

Conclusions (including caveats). The data presented here suggest that the control of external soil and dust track-in by removal of shoes and/or the use of a walk-off mat will reduce the lead exposure from house dust. Lacking any blood measurements, the impact these interventions may have had on childhood lead exposure are somewhat difficult to ascertain.

A.8 1990 St. Louis Retrospective Paint Abatement Study

Reference. Staes, C., Matte, T., Copley, G., Flanders, D., and Binder, S. (1994) "Retrospective Study of the Impact of Lead-Based Paint Hazard Remediation on Children's Blood Lead Levels in St. Louis, Missouri." *American Journal of Epidemiology*. 139(10):1016-1026.

Pertinent Study Objectives. The study attempted to assess, via a retrospective cohort study, the effectiveness of lead-based paint abatement in reducing children's blood-lead concentration.

Sampled Population. The sample population consisted of children under six years of age who were identified by the St. Louis City Health Department's Childhood Lead Poisoning Prevention Program as having a blood-lead concentration ≥ 25 μg/dL between January 1, 1989 and December 31, 1990. Moreover, the child had to reside, for six months prior and six months following diagnosis, in a dwelling with an identified lead-based paint hazard (at least one chipping or peeling paint surface with a lead content ≥ 0.7 mg/cm^2). Children who experienced chelation therapy were excluded. One hundred and eighty-five children met the criteria for the study, of which 71 had follow-up blood-lead measures 10-14 months following diagnosis.

Intervention Strategy. Intervention entailed the abatement of peeling or chipping lead-based paint (as identified by XRF to have a lead content ≥ 0.7 mg/cm^2) within the dwelling via enclosure or removal and replacement. No extensive clean-up procedures, other than removal of obvious remediation debris, accompanied abatement. Most likely, the families were not relocated from the dwelling during the intervention. In addition, educational interventions were initiated following the child's diagnosis of elevated blood-lead levels.

Measurements Taken. The blood-lead concentrations (PbB) were collected via venipuncture.

Study Design and Results. The geometric mean PbB among the 189 children selected was 33.6 μg/dL (range, 25-53 μg/dL). Seventy-one of these children had their blood-lead concentration measured 10-14 months following the initial diagnosis. 49 of these 71 children lived in dwellings which had been abated prior to follow-up measures. Blood-lead levels for children living in abated dwellings decreased by 23% (Table A.8-1). This decline was significantly ($p=0.07$) greater than the 12% reduction observed in geometric mean PbB among the 22 children residing in unabated dwellings.

Table A.8-1. Blood-Lead Concentration (μg/dl) by Abatement Group

Group	N	Range	Geo. Mean	Follow-up Geo. Mean	Percent Decline
Abated	49	25-51	34.9	26.7	23%
Unabated	22	28-45	35.1	30.9	12%

A multiple linear regression model predicting the change in geometric mean PbB at 10-14 months following diagnosis was fitted. The dwelling's abatement status at the time of the follow-up blood sample (e.g., abated or unabated) and whether the blood-lead level at diagnosis exceeded 35 μg/dL were statistically significant ($p<0.10$). The geometric mean PbB of children residing in abated dwellings was estimated to decrease 13% (95% CI, -25% to 1%) more than that of children residing in unabated dwellings. Moreover, the geometric mean PbB of children with an initial PbB ≥ 35 $\mu g/dL$ was estimated to decline by 17% (95% CI, -27% to -5%) more than that of children with lower PbB.

The decline in PbB 10-14 months following diagnosis was found to increase as the length of time since the lead-based paint abatement had occurred increased. The abatements usually occurred sometime after diagnosis. Finally, the reported 10-14 month post-diagnosis declines may be underestimates, since children with such extended follow-up measures were found to experience smaller declines in PbB at 2-4 months post-diagnosis than children without such extended measures.

Conclusions (including caveats). For lead-poisoned children in St. Louis, the decline in geometric mean PbB is greater for children whose dwellings undergo lead-paint hazard abatement than for children whose dwellings do not. The magnitude of the efficacy appears, however, to depend upon the child's initial blood-lead concentration. The follow-up measures were reported with respect to the timing of the diagnosis, rather than the abatement, so the potential masking effect of bone-lead mobilization cannot be assessed. The reference suggests many of the follow-up measures were collected less than six months following the abatement.

A.9 Boston 3-City Soil Abatement Project

Reference(s). Weitzman, M., Aschengrau, A., Bellinger, D., Jones, R., Hamlin, J. S., Beiser, A. (1993) "Lead-Contaminated Soil Abatement and Urban Children's Blood Lead Levels." *Journal of the American Medical Association.* 269(13):1647-1654.

Aschengrau, A., Beiser, A., Bellinger, D., Copenhafer, D., Weitzman, M. (1994) "The Impact of Soil Lead Abatement on Urban Children's Blood Lead Levels: Phase II results from the Boston Lead-In-Soil Demonstration Project." *Environmental Research.* 67:125-148.

Pertinent Study Objectives. This project endeavored to assess whether a significant reduction (≥1000 ppm) in the concentration of lead in residential soil results in a significant decrease (≥3 μg/dL) in the blood-lead concentration (PbB) of children residing at the premises.

Sampled Population. Volunteers were sought among children residing in areas in Boston already known to have high incidence of childhood lead poisoning and elevated soil-lead concentrations. A total of 152 children were enrolled, each satisfying the following criteria:

- less than or equal to four years of age,
- blood-lead concentration between 10 and 20 μg/dL with no history of lead poisoning, and
- a minimum median residential soil-lead concentration of 1500 μg/g (ppm).

Intervention Strategy. This project employed four lead hazard interventional procedures: 1) an initial one-time interior paint stabilization by removing exposed paint chips; 2) one-time interior dust abatement via wet mopping and HEPA vacuuming; 3) extensive soil abatement; and finally 4) interior and exterior lead-based paint abatement. Interior paint stabilization consisted of vacuuming loose paint areas with a HEPA vacuum, washing loose paint areas with a TSP solution, and painting the window wells with primer. Deleading consisted of removing leaded paint from mouthable surfaces below 5 feet, and making intact all paint above 5 feet inside the home, and exterior areas. Soil abatement consisted of removing surface soil to a depth of 6 in. for homes, and replacing with top soil containing minimum lead levels. Dispersal of soil during the abatement was retarded by wetting the soil, preventing track-in by workers, containing the abatement site with plastic, and washing all equipment.

Measurements Taken. Extensive environmental media and body burden samples were collected:

- composite core soil samples,
- vacuum dust samples,
- first draw water samples,
- interior and exterior paint assessment via portable XRF,
- venipuncture blood samples to assess blood lead concentration, and free erythrocyte protoporphyrin (FEP) and ferritin levels; and,
- hand-wipe samples.

Study Design and Results. Each child enrolled was randomly assigned to one of three experimental groups: Study (54 children), Comparison A (51 children), or Comparison B (47 children). During Phase I, the Study group received interior paint stabilization, interior dust abatement, and soil abatement. Comparison Group A received interior paint stabilization and interior dust abatement. Only interior paint stabilization was performed for Comparison Group B. During Phase II, which took place an average of 12 months after Phase I interventions, both comparison groups received soil abatement and all three experimental groups were offered lead-based paint abatement (Table A.9-1).

Table A.9-1. Schedule of Activities.

Phase	Activity	Study Group	Group A	Group B
Phase I	Baseline Blood Sample (9/89-1/90)	N=54/54	N=51/51	N=47/47
	Intervention I (9/89-1/90)	Soil and Interior Dust Abatement, Loose Paint Stabilization N=54/54	Interior Dust Abatement, Loose Paint Stabilization N=51/51	Loose paint Stabilization N=47/47
	Post-Abatement Blood Sample I (7/90-11/90)	N=54/54	N=49/51	N=46/47
Phase II	Intervention II (9/90-1/91)	Paint Deleading N=23/54	Soil Abatement N=47/49 Paint Deleading N=18/49	Soil Abatement N=42/46 Paint Deleading N=16/46
	Post-Abatement Blood Sample II (7/91-8/91)	N=33/54	N=32/49	N=26/46

Environmental media and body burden samples were collected at various times surrounding the interventional activities. Soil samples were also collected immediately following soil abatement to confirm its effectiveness.

During Phase I, the average blood-lead concentrations in all three experimental groups decreased at the first (6 months) post-abatement measurement. The statistically significant decreases were: 2.9 μg/dL for Study, 3.5 μg/dL for Comparison A, and 2.2 μg/dL for Comparison B. The following increases in average blood-lead concentration were recorded between the first and second (11 months) post-abatement measurements: 0.5 μg/dL for Study, 2.6 μg/dL for Comparison A, and 1.5 μg/dL for Comparison B. The increases for the two comparison groups were significantly different from zero. The mean dust-lead levels from hand-wipe samples for all groups followed a similar pattern, though they exhibited considerably greater variability.

By the end of Phase II, 91 children were still participating and living at the same premises as when they were enrolled. Of these children, 44 received both soil and lead-based paint abatement, 46 received only soil abatement, and 1 refused both interventions. Mean blood-lead concentrations in all three experimental groups were taken an average of 10 months post-abatement for Phase I and an average of 9 months post-abatement for Phase II. Although some premises underwent lead-based paint deleading during Phase II, no results on the additional efficacy of lead-paint abatements were reported.

For children whose premise underwent soil abatement only, mean blood-lead concentrations decreased between pre- and post-intervention measures (Table A.9-2). Study Group results are an average of 10 months post-abatement, and both comparison group results are an average of 9 months post-abatement. Two children in the Study Group and one child in Comparison Group B were excluded as outliers from this analysis.

Table A.9-2. Blood-Lead Concentration (μg/dL) by Experimental Group and Sample Period*

Group	Sample Size	Pre-abatement	Post-abatement	Mean Decline
Study	52	13.10	10.65	2.44
Comparison A	18	12.94	7.69	5.25
Comparison B	13	10.54	9.15	1.39
Study, Comparison A and B combined	83	12.66	9.77	2.89

* Study Group results are from Phase I and both Comparison Group results are from Phase II.

A repeated measures analysis was conducted for the restricted sample (N=31) of children from Comparison Group A (N=18) and Comparison Group B (N=13) who had PbB data at all three times. Study Group data was excluded for lack of a control period. Mean blood-lead concentrations decreased by 0.64 μg/dL during Phase I and another 3.63 μg/dL during Phase II (a 33.9% decline overall). For the 31 children of the restricted sample, variation was seen in the decline of blood-lead levels depending upon initial PbB (Table A.9-3). A trend in the magnitude of the decline in blood-lead levels was apparent, with larger declines observed in children with larger initial blood-lead levels.

Table A.9-3. Blood-Lead Concentration (μg/dL) by Experimental Group and Sample Period

Initial PbB	Change in PbB for		Overall Percentage Change
	Phase I	Phase II	
7-9	+0.30	-1.45	-18.1%
10-14	+0.18	-3.82	-31.8%
15-22	-2.50	-5.60	-30.3%

Although many yards had evidence of recontamination both at 6-10 and 18-22 months post-abatement, follow-up median soil-lead concentrations were generally less than 300 ppm (Table A.9-4). Similar results were observed for the comparison groups during Phase II. Dust-lead loadings were less consistent. Floor dust samples from within the residence were composited to produce a single dust measure for each residence. Dust-lead loadings declined significantly during the study

Table A.9-4. Surface Soil-Lead Concentration (ppm) by Experimental Group and Sample Period

Group	Period	Sample Size	Arith. Mean	Std. Dev.
Study	Pre-Abate.	35	2206	1123
	6-12 months Post-Abate.	35	141	299
	18-22 months Post-Abate.	34	160	115
Comparison A	Pre-Abate.	31	2358	1203
	6-12 months Post-Abate.	32	171	172
	18-22 months Post-Abate.	N/A	N/A	N/A
Comparison B	Pre-Abate.	26	2299	1129
	6-12 months Post-Abate.	26	180	127
	18-22 months Post-Abate.	N/A	N/A	N/A

(Table A.9-5). Comparable declines were seen in all three groups during Phase I, despite Comparison Group B not receiving any interior house dust abatement. Mean floor dust-lead loadings at 6-12 months post-abatement fell significantly for the Study Group ($P \leq 0.001$), during Phase I, but remained relatively unchanged for Comparison Groups A and B ($P=0.95$ and 0.15, respectively) during Phase II, despite the soil abatement. At 18-22 months post-abatement, mean levels in the Study Group rose, but were still significantly below baseline ($P=0.02$). No significant declines were seen in the lead loading, lead concentration, or dust loading measures for window well samples (Table A.9-6).

Conclusions (including caveats). These results demonstrate that a reduction of 2060 ppm in lead-contaminated soil around homes is associated with a modest decline in blood-lead levels. The magnitude of reduction in blood-lead level observed, however, suggests that lead-contaminated soil abatement is not likely to be a useful clinical intervention for the majority of urban children in the United States with low-level lead exposure. Furthermore, the decline is confounded with the efficacy of lead-based paint stabilization and seasonal variation in blood-lead levels.

Table A.9-5. Interior Floor Dust-Lead Loading ($\mu g/ft^2$) by Experimental Group and Sample Period*

Group	Period	Sample Size	Geo. Mean	Std. Dev.
Study	Pre-Abate.	21	769	54
	6-12 months Post-Abate.	14	96	35
	18-22 months Post-Abate.	11	207	22
Comparison A	Pre-Abate.	22	295	29
	6-12 months Post-Abate.	15	315	28
	18-22 months Post-Abate.	N/A	N/A	N/A
Comparison B	Pre-Abate.	22	261	45
	6-12 months Post-Abate.	12	295	27
	18-22 months Post-Abate.	N/A	N/A	N/A

Table A.9-6. Interior Window Well Dust-Lead Loading ($\mu g/ft^2$) by Experimental Group and Sample Period*

Group	Period	Sample Size	Arith. Mean	Std. Dev.
Study	Pre-Abate.	19	11524	143
	6-12 months Post-Abate.	15	28773	75
	18-22 months Post-Abate.	11	31420	41
Comparison A	Pre-Abate.	22	28373	58
	6-12 months Post-Abate.	15	15417	92
	18-22 months Post-Abate.	N/A	N/A	N/A
Comparison B	Pre-Abate.	21	21487	63
	6-12 months Post-Abate.	12	37205	102
	18-22 months Post-Abate.	N/A	N/A	N/A

* Lead loadings converted from μg Pb per m^2 to μg Pb per ft^2.

A.10 HUD Abatement Demonstration (HUD Demo) Study

Reference(s). U.S. Department of Housing and Urban Development. "The HUD Lead-Based Paint Abatement Demonstration (FHA)." Washington, D. C. August 1991.

U.S. Department of Housing and Urban Development. "Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately Owned Housing: Report to Congress." Washington, D. C. December 1990.

Pertinent Study Objectives. The study was designed to determine and evaluate the overall usability and effectiveness of various methods of lead-based paint abatement.

Sampled Population. These methods were tested between 1989 and 1990 in 172 FHA-foreclosed, single family housing units in seven urban areas: Baltimore, MD; Washington, D. C.; Seattle, WA; Tacoma, WA; Indianapolis, IN; Denver, CO; and Birmingham, AL. Three of these houses had only pilot abatements performed, while the other 169 were completely abated.

Intervention Strategy. Six abatement procedures were employed:

1) encapsulation - coating and sealing of surfaces with durable coatings,
2) abrasive removal - removal of lead-based paint using mechanical removal equipment,
3) hand-scraping with a heat gun - removal of lead-based paint using a heat gun to loosen the paint,
4) chemical removal - removal of lead-based paint using a chemical stripper,
5) enclosure - resurfacing or covering of the surface, and
6) removal and replacement - removing contaminated substrates and replacing with new or deleaded components.

Following the abatements, units were cleaned using HEPA vacuums and a high phosphate wash until HUD clearance standards were met. Debris was disposed of off-site. In practice, abrasive removal was not feasible for most surfaces and was not used.

Measurements Taken. X-Ray fluorescence (XRF) determination of lead content in paint, wet wipe sampling of surfaces within a defined area, and core soil samples were collected.

Study Design and Results. The specific units to be abated were selected by first identifying older housing likely to contain lead-based paint and then testing painted surfaces for lead using portable XRF. Units included in the study were those found to have a large number of structural components covered by paint with a high concentration ($\geq$ 1.0 μg/cm^2) of lead. An abatement strategy, consisting of decision rules for choice of abatement method, was randomly assigned to each house. The method used to characterize the unit abatement strategy was always the first-choice method and was used on all components to the extent feasible. Second, third, and fourth choice methods were specified for each strategy. Because of the diversity of housing components containing lead-based paint, it was generally true that no single abatement method could be used uniformly throughout a given housing unit.

Once the lead-based paint had been abated from a component and the area cleaned, clearance wipe samples were collected to verify the abatement. The resulting dust-lead loadings were compared to the appropriate standard in the HUD Guidelines: 200 μg/ft^2 for floors, 500 μg/ft^2 for window sills, and 800 μg/ft^2 for window wells. Eighty percent of floor wipe clearance samples passed by measuring below the 200 μg/ft^2 standard (Table A.10-1). Units predominantly abated using replacement methods were most often measured to have floor dust-lead loading below the standard, 87.5%. The differences seen in the rates at which particular methods failed to meet the standard are statistically significant ($p < 0.001$).

Table A.10-1. Distribution of Wipe Samples ($\mu g/ft^2$) on Floors by Clearance Standard on Initial Wipe Test by Predominant Unit Abatement Strategy

Wipe Value	Encaps.	Enclose	Chemical	Scrape w Heat Gun	Replacement	Total
< 200 $\mu g/ft^2$	188 (86.2%)	96 (80.0%)	276 (77.3%)	163 (71.2%)	203 (87.5%)	926 (80.1%)
≥ 200 $\mu g/ft^2$	30 (13.8%)	24 (20.0%)	81 (22.7%)	66 (28.8%)	29 (12.5%)	230 (19.9%)
ALL	218 (100%)	120 (100%)	357 (100%)	229 (100%)	232 (100%)	1156 (100%)

The highest failure rates among window sill wipe clearance samples were for chemical stripping and heat gun removal units (Table A.10-2). Overall, the window sill samples passed 84.7% of the time. There were significant differences among the different abatement methods.

Table A.10-2. Distribution of Wipe Samples ($\mu g/ft^2$) on Window Sills by Clearance Standard on Initial Wipe Test by Predominant Unit Abatement Strategy

Wipe Value	Encaps.	Enclose	Chemical	Scrape w Heat Gun	Replacement	Total
< 500 $\mu g/ft^2$	157 (95.2%)	78 (91.8%)	173 (75.9%)	124 (75.6%)	137 (92.6%)	669 (84.7%)
≥ 500 $\mu g/ft^2$	8 (4.8%)	7 (8.2%)	55 (24.1%)	40 (24.4%)	11 (7.4%)	121 (15.3%)
ALL	165 (100%)	85 (100%)	228 (100%)	164 (100%)	148 (100%)	790 (100%)

Window well clearance wipe samples were more problematic than the other sample types; only 65% were measured below 800 $\mu g/ft^2$ (Table A.10-3). Units predominantly abated using chemical stripping and heat gun removal methods had approximately 45% of their clearance wipes above the standard. This is significantly different than the 21% failure rate encountered for units predominantly abated using replacement methods.

Table A.10-3. Distribution of Wipe Samples ($\mu g/ft^2$) on Window Wells by Clearance Standard on Initial Wipe Test by Predominant Unit Abatement Strategy

Wipe Value	Encaps.	Enclose	Chemical	Scrape w Heat Gun	Replacement	Total
< 800 $\mu g/ft^2$	75 (74.3%)	45 (76.3%)	95 (54.3%)	61 (55.5%)	79 (79.0%)	355 (65.1%)
≥ 800 $\mu g/ft^2$	26 (25.7%)	14 (23.7%)	80 (45.7%)	49 (44.5%)	21 (21.0%)	190 (34.9%)
ALL	101 (100%)	59 (100%)	175 (100%)	110 (100%)	100 (100%)	545 (100%)

Core soil samples were collected before and after the abatement procedures were employed. An examination of a subset of 130 homes suggests that the abatement procedures may have elevated lead levels in the surrounding soil (Table A.10-4).

Table A.10-4. Comparison of Pre- and Post-Abatement Soil Lead Concentration (ppm) by Urban Area

Urban Area	Number of Homes	Arithmetic Mean Change in PbS	Number with Increased PbS Levels	Percent with Increased PbS Levels
Baltimore / Washington	17	179.67	11	64.7
Birmingham	23	61.76	12	52.2
Denver	38	54.55	28	73.7
Indianapolis	27	122.59	24	88.9
Seattle / Tacoma	25	227.39	22	88.0

Conclusions (including caveats). Five of the six methods successfully abated the lead-based paint hazard, but required varying degrees of effort. Abrasive sanding was not successfully implemented because the machines kept clogging. If encapsulation and enclosure methods are found to exhibit long-term efficacy, their low-cost and minimal waste make them ideal for most abatement tasks. There is evidence that soil-lead levels surrounding the residences increased due to the abatement procedures.

A.11 Comprehensive Abatement Performance (CAP) Study

Reference. Battelle Memorial Institute and Midwest Research Institute, "Comprehensive Abatement Performance Study." Draft Final Report to U. S. Environmental Protection Agency. January, 1994.

Buxton, B.E., Rust, S.W., Kinateder, J.G., Schwemberger, J.E., Lim, B., Constant, P., and Dewalt, G. "Post-Abatement Performance of Encapsulation and Removal Methods for Lead-Based Paint Abatement", Lead in Paint, Soil, and Dust. Health Risks, Exposure Studies, Control Measures, Measurement Methods, and Quality Assurance, ASTM STD 1226, Michael E. Beard and S.D. Allen Iske, Eds., American Society for Testing Materials, Philadelphia. 1994.

Pertinent Study Objectives. The CAP Study sought to assess the long-term effectiveness of two lead-based paint abatement strategies: 1) encapsulation and enclosure methods, and 2) removal methods.

Sampled Population. Fifty-two FHA foreclosed, single family residences in Denver, Colorado were examined. Thirty-five of the residences were abated using the aforementioned methods as part of the HUD Abatement Demonstration (HUD Demo) Study. The remaining 17 residences were control (unabated) homes identified in the HUD Demo Study to contain little or no lead-based paint.

Intervention Strategy. Surfaces identified via XRF to contain lead-based paint were abated using either encapsulation, enclosure, or one of four removal methods (chemical stripping, abrasive stripping, heat-gun stripping, and complete removal or replacement of painted components).

Measurements Taken. Vacuum dust samples within a specified area (to permit both lead loading and lead concentration calculations) and core soil samples were collected.

Study Design and Results. Because of the diversity of housing components containing lead-based paint, it was generally true that no single abatement method could be used uniformly throughout a given housing unit. For the CAP Study, each house was primarily classified according to the abatement category (i.e., encapsulation/enclosure versus removal methods) accounting for the largest square footage of interior abatement. However, at many HUD Demonstration houses, a great deal of exterior abatement was also performed. Therefore, the data interpretation also considered which specific methods were used on both the interior and exterior of the house.

Dust-lead levels were measured in two abated and one unabated room in each abated residence, and two rooms in each control residence. In each room, air duct, floor, window sill, and window well samples were obtained. Interior and exterior dust samples were also collected at the entryway to the residence. Soil samples were taken at the foundation, entryway, and boundary of the home.

The study results may be summarized as follows:

- Lead levels were often found to be higher in abated houses than in control houses, primarily in sampling locations where no abatements were performed. The most significant differences in dust-lead loadings were found for air duct vacuum samples and exterior entryway vacuum samples. The most significant differences in lead concentrations were found for air duct vacuum samples (Table A.11-1).

- Soil-lead concentrations were significantly higher at abated houses than at control houses (Table A.11-1).

Table A.11-1. Summary of Effects of Significant Primary Abatement Factors

Component	Geometric Mean in Control Houses Based on Model Estimates			Ratio of Levels in Abated Houses[1] to Those in Control Houses			Ratio of Levels in E/E Houses to Those in Removal Houses		
	Lead Load $\mu g/ft^2$	Lead Conc. $\mu g/g$	Dust Load mg/ft^2	Lead Load $\mu g/ft^2$	Lead Conc. $\mu g/g$	Dust Load mg/ft^2	Lead Load $\mu g/ft^2$	Lead Conc. $\mu g/g$	Dust Load mg/ft^2
Dust									
Air Duct	76	332	202	4.70**	1.59**	3.11**	3.99**	2.01**	1.80
Window Well	1604	851	1857	0.86	0.98	0.88	0.54	1.46	0.37
Window Sill	38	416	92	1.84	1.70	1.09	2.51	1.77	1.42
Floor (Wipe)	11.3	...	...	...	...	...	0.93	...	...
Floor (Vacuum)	16	137	118	1.76*	1.03	1.65*	2.02**	1.30	1.55
Interior Entryway	191	183	1054	1.05	0.85	1.19	1.15	0.95	1.24
Exterior Entryway	220	184	1152	2.24*	1.19	1.95**	1.09	1.01	1.07
Soil									
Entryway (Soil)	...	126	...	...	1.48*	...	...	1.26	...
Foundation (Soil)	...	85	...	...	1.88**	...	...	0.70	...
Boundary (Soil)	...	86	...	...	1.63**	...	...	1.27	...

1 For interior samples, these represent ratios of levels in abated rooms of abated houses to those in control houses.
* Significant at 10% level.
** Significant at 5% level.

- Only for air duct samples was there a significant difference in lead concentrations between houses abated by different methods. The most significant differences in dust-lead loadings were found for air duct vacuum samples and floor vacuum samples. However, it should be noted that for almost every sample type where lead concentrations were higher in abated houses than in control houses, lead concentrations were also typically higher in houses abated by encapsulation/enclosure methods than in houses abated by removal methods. The same was true for lead loadings. (Table A.11-1).

- Lead levels were often lower, and sometimes significantly lower, in control rooms of abated houses (i.e., rooms that did not require abatement) than in abated rooms of these same houses, although the differences observed were only of marginal significance (10% level). There were no statistically significant differences in lead concentrations, and lead loadings were (marginally) lower in window well samples and floor vacuum samples. (Table A.11-2)

- Floor dust-lead loadings in abated houses were below the HUD interim standard of 200 $\mu g/ft^2$, as well as the EPA guidance level (July 14, 1994) of 100 $\mu g/ft^2$. Window sill dust-lead loadings also were below the HUD interim standard of 500 $\mu g/ft^2$. However, window well dust-load loadings in both abated and unabated houses were typically greater than the HUD interim standard of 800 $\mu g/ft^2$.

Table A.11-2. Ratio of Levels of Control Rooms to Those in Abated Rooms

Component	Lead Loading	Lead Concentration	Dust Loading
Air Duct	0.73	0.79	0.91
Window Channel	0.39*	0.61	0.65
Window Stool	0.67	0.69	0.96
Floor (Vacuum)	0.56*	0.87	0.65*
Interior Entryway	1.63	1.28	1.31

* Significant at the 10 percent level.

Conclusions (including caveats). While, lead levels typically remained higher for abated houses than for control homes the abatement methods appear efficacious in the long-term. The study results also indicate that the lead levels after encapsulation/ enclosure abatement were typically, though not significantly, higher than those with removal abatement. When interpreting these results it should be noted that encapsulation/enclosure houses typically had larger amounts of abatement performed than removal houses. Therefore, the differences in lead levels noted above may be largely a result of the more severe initial conditions in encapsulation/enclosure houses, that is, the greater amount of abatement required in encapsulation/enclosure houses. In addition, abated houses were, on average, 17 years older than control houses. Thus, differences in soil-lead levels between abated and control houses could be due to the differences in age, the current or past presence of lead paint, or both.

A.12 Milwaukee Retrospective Paint Abatement Study

References. Schultz, B.D. (1993). "Variation in Blood Lead Levels by Season and Age." Draft Memorandum on data from the Milwaukee Blood Screening Program. June, 1993.

Pertinent Study Objectives. Examine the effectiveness of the lead-based paint abatement strategies implemented in the Milwaukee area in 1989-1992.

Sampled Population. Children residing in houses whose lead-based paint hazard has been at least partially abated.

Intervention Strategy. Damaged, painted surfaces with lead loadings exceeding 1.0 mg/cm^2 were abated. The exact method of abatement was not available. Clean-up procedures varied depending upon the practices of the particular abatement contractor.

Measurements Taken. Pre- and post-abatement blood samples were collected. Most of the post abatement samples were collected 3 to 12 months following abatement.

Study Design and Results. Only preliminary results are available at this time. Blood-lead concentrations were collected from 104 children. The arithmetic mean blood-lead concentration fell from 34 $\mu g/dL$ pre-abatement to 26 $\mu g/dL$ post-abatement which represents a 24% decline.

Conclusions (including caveats). The above results seem to imply that lead-based paint abatement does reduce blood-lead levels. However, as mentioned previously the results are preliminary at this time.

A.13 New York Chelation Study

References. Markowitz, M.E., Bijur, P.E., Ruff, H.A., Rosen, J.F. (1993). "Effects of Calcium Disodium Versenate ($CaNa_2EDTA$) Chelation in Moderate Childhood Lead Poisoning." *Pediatrics.* 92(2):265-271.

Ruff, H.A., Bijur, P.E., Markowitz, M.E., Ma, Y., Rosen, J.F. (1993). "Declining Blood-Lead Levels and Cognitive Changes in Moderately Lead-Poisoned Children." *Journal of the American Medical Association.* 269(13):1641-1646.

Rosen, J.F., Markowitz, M.E., Bijur, P.E., Jenks, S.T., Wielopolski, L., Karlef-Ezra, J.A., and Slatkin, D.N. (1991). "Sequential Measurements of Bone Lead Content by L-X-Ray Fluorescence in $CaNa_2EDTA$-Treated Lead-Toxic Children." *Environmental Health Perspectives.* 91:57-62

Pertinent Study Objectives. The study was an effort to ascertain the efficacy of a particular chelation therapy procedure on moderately lead-poisoned children. Effectiveness was assessed both short-term (6-7 weeks post-treatment) and long-term (6 months post-treatment).

Sampled Population. The study examined a subset of the children, 1 to 7 years of age, referred by their physicians to the Montefiore Medical Center Lead Clinic. A child was eligible for the study if their blood-lead levels were between 25 μg/dL and 55 μg/dL, their erythrocyte protoporphyrin (EP) levels were greater than 35 μg/dL and the child had not required chelation therapy before.

Intervention Strategy. Paint hazard abatements were initiated at the child's residence following identification that the child was moderately lead-poisoned. The abatements were either completed before the child was released from the hospital following chelation therapy or lead-free alternative housing was found until the abatement had been completed. The specific details of the abatement procedure were not cited in the reference.

Measurements Taken. Measurements of the lead-based paint loading on interior residential surfaces were collected via XRF both at enrollment and six weeks following enrollment (lead-based paint abatement was performed and completed within that time). LXRF tibial bone, EP, blood, and urinary measurements were collected from each child at enrollment, 6-7 weeks post-enrollment, and 6 months post-enrollment. In addition, an index of cognitive functioning was administered at about the same time as the biochemical measurements.

Study Design and Results. A total of 201 children were enrolled in this study. Each enrolled child was administered an 8-hour edetate calcium disodium ($CaNa_2EDTA$) lead mobilization test (LMT) and tested for iron deficiency or depletion. A positive LMT suggested chelation therapy might prove effective in reducing their blood-lead levels, and iron deficiency was treated with iron supplements. The New York Department of Health used visual inspection and XRF measurements to assess whether the child's residence required lead-based paint abatement. It was determined that the residences of 89% of the children in this study required abatement.

Table A.13-1. Pre-Treatment Measures by Treatment Group

Measure	Chelated Group (n = 71)		Control Group (n = 103)	
	Mean	Standard Deviation	Mean	Standard Deviation
Blood-Lead Level (μg/dL)	37.3	8.1	29.0	5.6
EP Level (μg/dL)	143.3	88.0	78.0	43.2
Bone-Lead CNET[1]	191.4	105.4	125.3	87.1
HES[2]	164.4	193.8	110.6	153.3

[1] Corrected net counts.

[2] Home environment scale (XRF reading multiplied by 0-3 score for paint's condition, 0 = intact, 3 = peeling, summed across all surfaces assessed within the residence).

This abstract considers the reported results for three overlapping subsets of this study. These subsets were cited in the three journal articles outlining the results of this study. The first subset is addressed in Markowitz et al (1993), the second in Ruff et al (1993), and the third in Rosen et al (1991).

The first set of analyses examined a subset of 174 children. Seventy-one of the children had a positive LMT and underwent chelation therapy. The remaining 103 children underwent no chelation therapy and were used as a control population. Twenty-two of the chelated children and 50 of the non-chelated children were administered iron supplements. For all the children enrolled, body burden and environmental measures were collected (Table A.13-1).

Six to seven weeks following enrollment, mean blood-lead levels among the 103 non-chelated children had fallen 2.5 μg/dL and mean bone-lead levels had fallen 3.3 CNET (Table A.13-2). An analysis of the measured changes found significant differences for blood-lead concentration, bone-lead counts, and EP concentration between the chelated and control groups ($p < 0.05$). The differences in HES were not statistically significant between the two groups. Average HES did fall from 129 to 82 among the abated residences, but 79% of the residences were still identified as having a problem with peeling paint following abatement. Recall that the control and chelated groups had significantly different initial mean levels for blood-lead, bone-lead, and EP levels (Table A.13-1). To assess this disparity, the declines six weeks post-enrollment were re-examined after developing chelated and

Table A.13-2. Mean Change in Body Burden Measures at 6 Weeks Post-Treatment, by Treatment Group

Measure	Chelated Group (n = 71)	Control Group (n = 103)
Blood-Lead (μg/dL)	-7.2	-2.5
Bone-Lead (CNET)	-44.9	-3.3
EP (μg/dL)	-37.4	-12.6

control groups matched by initial levels. The reanalysis found the declines were not significantly different across the two groups for any of the measured parameters.

The second subset consisted of 154 of the 201 children enrolled, 126 of which had complete data. Sixty of the 154 children were iron deficient, 93 underwent no chelation therapy, 35 were treated once, 19 were treated twice, and 7 were chelated three times. In addition to results at enrollment and 6-7 weeks post-enrollment, 6 month post-enrollment measurements were cited for this subset (Table A.13-3). Despite finding no association between blood-lead levels and cognitive index (CI) at enrollment, the authors did note that mean CI increased to a small but significant degree over the six months following enrollment. More importantly, though changes in CI were not related to changes in blood-lead level short-term, CI was stated to increase as blood-lead concentration decreased long-term (Table A.13-4). Furthermore, the authors suggested that CI increased approximately 1 point for every 3 μg/dL decrease in blood-lead level.

Table A.13-3. Mean and Standard Deviation Measures, by Time Point

Measure[1]	Enrollment	6 Weeks Post-Enrollment	6 Months Post-Enrollment
Blood-Lead Level (μg/dL)	31.2 (6.5)	26.9 (6.3)	23.9 (6.5)
Cognitive Index	79.0 (13.0)	83.1 (13.6)	82.6 (13.3)
Bayley Score (n=56)	76.9 (14.0)	78.4 (14.1)	76.6 (13.3)
Stanford-Binet Score (n=53)	83.5 (10.2)	87.0 (10.3)	88.1 (11.2)

1 Subset of 126 children seen at all three time points.

Table A.13-4. Mean and Standard Deviation Cognitive Index, by Treatment Group and Time Point

Treatment Group	Enrollment	6 Month Post-Enrollment
Non-Chelated (n=80)	78.8 (11.4)	81.5 (12.3)
Chelated (n=49)	79.2 (15.1)	83.8 (14.8)

The third subset was of 59 children, 30 of which were non-chelated. In addition to enrollment and 6-7 week post-enrollment results, 6 month post-enrollment results for blood-lead, bone-lead, and EP levels were reported (Table A.13-5). Some of the 29 chelated children in the subset underwent two rounds of chelation therapy. Mean blood-lead levels among the 30 non-

Table A.13-5. Mean Blood-Lead, Bone-Lead and EP Levels, by Treatment Group and Sampling Period

Blood-Lead Level (μg/dL)	Control (n = 30)	Chelated Once[1]	Chelated Twice[1]
At Enrollment	29	37	42
After 6 Weeks	23	26	32
After 6 Months	21	24	26

Bone-Lead (CNET)	Control (n = 30)	Chelated Once[1]	Chelated Twice[1]
At Enrollment	117	211	217
After 6 Weeks	120	132	161
After 6 Months	121	125	115

EP (μg/dL)	Control (n = 30)	Chelated Once[1]	Chelated Twice[1]
At Enrollment	80	110	138
After 6 Weeks	82	100	88
After 6 Months	42	45	43

1 References did not specify the sample size of these two groups, though together they equal the 29 chelated children.

chelated children had fallen 6 μg/dL by 6 weeks post-enrollment and an additional 2 μg/dL by 6 months post-enrollment. Mean bone-lead levels did not change significantly among the non-chelated children neither by 6-weeks nor 6-months post-enrollment.

Conclusions (including caveats). Since the lead-based paint abatements were not the focus of this study, hypotheses surrounding the abatement's efficacy were not tested. The reported results, however, did suggest the abatements were effective. There is evidence that blood-lead, bone-lead and EP levels declined following the partial abatement of residential lead-based paint. More importantly, the blood-lead declines were associated with increases in cognitive index among moderately lead-poisoned children. In addition, the study's authors determined that initial bone-lead levels impacted the extent to which bone-lead declined following intervention. It should be noted, however, that seasonal variation may have played a role in the body burden declines cited 6 months post-enrollment.

A.14 Milwaukee Retrospective Educational Intervention Study

Reference. Schultz, B.D. (1995) Personal Communication, April, 1995.

Pertinent Study Objectives. This study sought to assess the effectiveness of in-home education efforts in Milwaukee in 1991-1994.

Sampled Population. The sample population consists of 431 children under 6 years of age, who were identified by the Milwaukee Health Department as having initial blood-lead concentrations between 20-24 μg/dL, who had a follow-up blood-lead measure and had not moved before the follow-up measure. Of these, 195 children received and in-home educational visit and had a follow-up blood-lead measure after the in-home visit. The control group of 236 children did not receive a health department in-home visit, either because they were identified before the educational outreach program was in place, or because the family could not be contacted after several attempts.

Intervention Strategy. The in-home educational visits were conducted by para-professionals. The visits lasted approximately one hour and educated the families on nutrition, behavior change, and housekeeping recommendations to reduce childhood lead body burden.

Measurements Taken. Venous and capillary blood-lead measurements were taken.

Study Design and Results. Follow-up blood-lead concentrations (PbB) were collected 2-15 months after initial PbB measures. The arithmetic mean blood-lead concentration for the Educational Outreach group declined by 18 percent, as compared to the Control group decline of 5 percent (Table A.14-1). The difference between these decline is highly statistically significant. Also, blood-lead levels decreased for 154 of the 195 (79%) children in the Educational Outreach group, compared to 124 of the 236 (53%) children in the Control group. Blood-lead concentrations were adjusted for the effects of age and seasonal variations.

Table A.14-1. Blood-Lead Concentrations (μg/dL) by Study Group

Study Group	N	Mean Initial PbB (μg/dL)	Mean Decline in PbB	Mean % Decline in PbB
Educational Outreach	195	22	4	18
Control	236	22	1	5

Conclusions (including caveats). The results seem to imply that educational intervention does appear to reduce blood-lead levels. Although children receiving visits receive significant health benefits on average, their blood-lead concentrations were still usually above 10 μg/dL and even above 15 μg/dL.

A.15 Granite City Educational Intervention Study

Reference. Kimbrough, R.D., LeVois, M., and Webb, D.R. (1994) "Management of Children with Slightly Elevated Blood-Lead Levels." *Pediatrics*. 93(2):188-191.

Statement of Dr. Renate D. Kimbrough, Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, U. S. House of Representatives, June 9, 1992.

Kimbrough, R.D., Personal Communication, January, 1995.

Illinois Department of Public Health (IDPH) (1995). Additional information on the Granite City Educational Intervention Study was provided by John R. Lumpkin, M.D., Director, and the Staff of the IDPH.

Pertinent Study Objectives. The study's objectives included an effort to evaluate the efficacy of educational interventions to reduce blood-lead concentrations (PbB) in exposed individuals.

Sampled Population. 827 volunteers, including 490 children under six years of age, were recruited from 388 households in Granite City, Illinois. Most homes in the community were built prior to 1920 and contained lead-based paint. In addition, a secondary lead smelter was closed in 1983 and had been declared a superfund site.

Intervention Strategy. During home visits where the entire family was present, extensive and intensive educational efforts were aimed at the children and families exposed to elevated levels of lead in the surrounding environment. Instruction included identifying where lead-based paint was commonly found, how to perform house cleaning procedures, and hygienic procedures for young children. Suggestions were also made to carefully remove peeling paint or make it inaccessible by installing barriers.

Measurements Taken. Venous blood samples, soil samples, dust samples from within the residence, tap water samples, and an assessment of the lead content in interior paint were collected.

Study Design and Results. Of the 490 children under age 6, 78 (16%) had PbB levels greater than 9 μg/dL. Of these 5 had PbB levels greater than 25 μg/dL. When possible, follow-up measures were collected at four months and twelve months after the initial sample. In the interim between the initial and four month samples, the families of these children received extensive counseling in the prevention of lead exposure.

These follow-up measures were available for a subset of 59 children. Two groups were considered for analysis. The first group consisted of all 59 children, and the second group consisted of a total of 24 who had data for all three measures. Mean blood-lead concentrations in both groups decreased significantly (P=0.001) at the four month post-abatement measurement, and rose again by the twelve month measure (Table A.15-1). Despite the rise in blood-lead levels, the 12 month averages remained significantly (P=0.001) below initial levels. For all 59 children, variation was seen in the decline of blood-lead concentrations depending upon initial PbB (Table A.15-2). A trend in the magnitude of the decline in blood-lead levels was apparent, with larger declines observed in children with larger initial blood-lead levels.

In addition, four month follow-up blood-lead concentrations were significantly lower than initial levels for a small number of older children with elevated blood-lead levels. For 7 children aged 6 to 14 years, the arithmetic mean decrease was 5.9 μg/dL, and for 3 children 15 years or older, blood-lead levels decreased 7.0 μg/dL.

Conclusions (including caveats). There is evidence to suggest that the educational efforts lowered blood-lead levels. These differences, however, cannot be separated from possible seasonal or age variations. In addition, the full implications of the observed declines in blood-lead concentration are somewhat difficult to ascertain without a control group.

Table A.15-1. Blood-Lead Concentration (μg/dL) by Time Period

Timing Period	Measurement	Sampling Group	
		All Children	Complete
Pre-intervention	N	59	24
	Geo. Mean (LSD)	13.83 (0.31701)	14.17 (0.37112)
	Arith. Mean (SD)	14.6 (5.37)	15.25 (6.81)
4 Months Post-intervention	N	54	24
	Geo. Mean (LSD)	7.36 (0.33440)	7.72 (0.29324)
	Arith. Mean (SD)	7.76 (2.42)	8.03 (2.20)
	Arith. Decline	6.83	7.23
	Arith. % Decline	44.8%	47.4%
12 Months Post-intervention	N	29	24
	Geo. Mean (LSD)	9.08 (0.33822)	8.73 (0.34014)
	Arith. Mean (SD)	9.58 (3.08)	9.20 (2.94)
	Arith. Decline	5.59	6.05
	Arith. % Decline	32.1%	39.7%

Table A.15-2. Blood-Lead Concentration (μg/dL) by Initial PbB

Initial PbB	4 Months			12 Months		
	Sample Size (N)	Arith. Mean Decline	Percent Decline (%)	Sample Size (N)	Arith. Mean Decline	Percent Decline (%)
<10*	10	4.11	42.6	4	1.68	17.2
10-15	26	5.10	41.7	14	2.87	24.1
15-20	9	7.62	43.5	6	8.07	46.3
20-25	7	11.69	55.0	3	8.67	42.5
>25	2	22.45	65.9	2	20.40	59.9

* All children were between 9 and 10 μg/dL.

A.16 Milwaukee Prospective Educational Intervention Study

Reference. Schultz, B.D. (1995) Personal Communication, April, 1995.

Pertinent Study Objectives. This study sought to assess the effectiveness of in-home education efforts in Milwaukee in 1993.

Sampled Population. Children selected were between 9 and 72 months old, had not received a in-home visit in the previous year, and their dwelling had not undergone an abatement within the previous year. Three separate groups of children were examined. The Educational Outreach Group contained 54 children whose initial PbB was between 20-24 μg/dL. For comparison, a Control Group of 122 children was selected from those previously identified in the Milwaukee Retrospective Study, whose follow-up blood-lead measurement was taken within 3 months of the initial measurement. The Pre-abatement Educational Outreach Group consisted of 28 children who had an initial PbB between 25-40 μg/dL. Abatements were required for these children, but had not been implemented at the time of the in-home visit and follow-up PbB measurement. Follow-up blood-lead measures were collected an average of 2 months after the in-home visit for the Educational Outreach and Control Groups and an average of 2 to 6 months for the Pre-abatement Educational Outreach Group.

Intervention Strategy. The in-home educational visit was conducted by para-professionals. The visits lasted approximately one hour and educated the families on nutrition, behavior change, and housekeeping recommendations to reduce childhood lead body burden. No paint abatements were performed in these homes. Children in the 25-40 μg/dL range received an additional visit from a Public Health Nurse, who conducted a general health assessment of the child/family and also answered any questions about lead.

Measurements Taken. Venous and capillary blood-lead measurements were taken.

Study Design and Results. Both the Educational Outreach and Control Groups had initial mean PbB levels of approximately 22 μg/dL. The Educational Outreach Group mean decline was about 3 μg/dL more than the Control Group at the 2 month follow-up. This difference was statistically significant. Mean blood-lead concentrations for the Pre-abatement Educational Outreach Group declined by 19.3% (from 28.9 to 22.6 μg/dL). Both the Educational Outreach and Pre-abatement Educational Outreach Groups had approximately the same percentage drop. However the Pre-abatement Group had a greater absolute decline, suggesting greater declines with greater initial blood-lead concentrations. Blood-lead levels were adjusted for the effects of age and seasonal variations.

Conclusions (including Caveats). These results seem to imply that educational intervention does appear to reduce blood-lead levels, although blood-lead concentrations usually remained above 10 μg/dL.

APPENDIX B

REVIEW OF ABATEMENT METHODS ASSOCIATED WITH TEMPORARY INCREASES IN BLOOD-LEAD LEVELS

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APPENDIX B

REVIEW OF ABATEMENT METHODS ASSOCIATED WITH TEMPORARY INCREASES IN BLOOD-LEAD LEVELS

In some cases residential lead-based paint abatement has resulted in a temporary increase in blood-lead (PbB) levels in children and abatement workers. Abatement methods most associated with this phenomenon include sanding, dry scraping, and the use of heat guns or torches to soften paint so that it may be scraped more easily. These procedures can create large amounts of lead contaminated dust or airborne lead, which is not easily removed from the residence.

The following paragraphs provide short descriptions of the use of sanding, dry scraping, heat guns, and torches in lead-based paint abatements, followed by a summary of the scientific evidence on each abatement method. In addition to the prospective and retrospective studies cited, there are many case reports in the literature that document elevated PbB in children or abatement workers following the removal of leaded paint using these methods (e.g., Rey-Alvarez and Menke-Hargrave, 1987; Fischbein, et al, 1981; Feldman, 1978; Amitai, et al, 1987). Other sources document such elevated PbB levels, but do not associate the elevated levels with specific abatement practices (e.g., Rabin, et al, 1994; Swindell, et al, 1995).

In some cases, sample personal air exposure (PAE) data were available. These data may be compared to the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 50 $\mu g/m^3$ or the OSHA action limit of 30 $\mu g/m^3$. The OSHA PEL is the current standard to protect construction workers against chronic exposure to airborne lead. Medical monitoring of PbB levels is required for workers who are exposed to lead levels above the action limit. Both the PEL and action limit are based on time weighted average exposure over an eight hour work day.

B.1 SANDING

B.1.1 <u>Description of Sanding</u>

Leaded paint can be removed by manual sanding, or machine sanding with ordinary circular, reciprocating, belt, or palm sanders. Related methods include the use of needle guns, grinders, brushes, or abrasive blasting tools to abrasively or percussively remove leaded paint. Power tools used for lead-based paint abatement are sometimes fitted with a high-efficiency particulate accumulator (HEPA) dust collection system. In some instances, the surface is misted to contain dust and avoid aggravating the lead hazard. Use of a respirator is recommended when applying any of these abrasive removal methods. A more powerful respirator may be required when using power tools without HEPA dust collection systems (Labor, 1993).

B.1.2 Scientific Evidence on Sanding

Use of this method was limited in the U.S. Department of Housing and Urban Development (HUD) Demonstration, because many surfaces were not flat, or could not endure abrasive action (e.g. drywall). When applied, abrasive removal by machine sanding was found to generate a large amount of potentially hazardous dust and HEPA attachments to collect this dust were found to be ineffective in most instances (HUD, 1991).

Personal air lead exposure data, for housing abatement projects where power tools with HEPA dust collection systems were in use, were reported for 28 samples, averaging 185 $\mu g/m^3$ with individual sample exposures ranging from .2 $\mu g/m^3$ to 1596 $\mu g/m^3$. PAEs for vacuum blasting were reported for 4 samples, averaging 169 $\mu g/m^3$ with individual sample exposures ranging from 2 $\mu g/m^3$ to 665 $\mu g/m^3$ (Labor, 1993).

Sanding is frequently used in combination with other abatement methods. Consequently, studies reporting results from such abatements do not always distinguish among the methods applied. Additional results on abatements where sanding was employed, including documented increases in PbB levels of resident children following abatement, are presented in the sections on dry scraping and torch methods.

B.2 DRY SCRAPING

B.2.1 Description of Dry Scraping

Dry scraping is the traditional method of surface preparation for home renovation and remodeling, whereby paint is removed by hand-scraping with a putty knife or similar tool. In terms of lead-based paint abatement, this method is time-consuming and generates a large amount of lead containing dust. Wet scraping, where the surface is misted to reduce dust levels, is preferred for work on lead-based paint surfaces (HUD, 1994). However, dry scraping usually has been deemed acceptable for small surfaces, e.g. near electrical outlets.

B.2.2 Scientific Evidence on Dry Scraping

In a retrospective study of preschool children in Boston, dry scraping and sanding were associated with an increase of 9.1 $\mu g/dL$ in the PbB levels of 41 children during abatement, compared with their pre-abatement levels. Abatements were performed in accordance with state regulations at the time, which required that lead-based paint be removed from or permanently covered on all chewable surfaces below 4 feet and that loose or peeling paint be made intact on all other surfaces. For these abatements, dry scraping was used to remove paint and sanding was used to feather the edges to prevent additional deterioration and prepare the surface for repainting. As such, the effects of dry scraping and sanding cannot be isolated. The PbB level during abatement was determined about 2 months after the pre-abatement PbB measurement. Abatements were usually completed in 3 to 4 months (Amitai, et al, 1991).

PAEs for dry scraping were reported for 6 samples, averaging 45 $\mu g/m^3$ with individual sample exposures ranging from 6 $\mu g/m^3$ to 167 $\mu g/m^3$ (Labor, 1993).

B.3 HAND SCRAPING WITH HEAT GUN

B.3.1 Description of Hand Scraping with Heat Gun

This procedure entails using a heat gun to soften the paint, which may then be removed by hand-scraping. Heating the paint can generate high levels of volatilized lead, which creates a risk hazard to the abatement worker and makes the final cleanup process more difficult. Commercial heat guns typically produce air temperatures of approximately 1000°F at the gun nozzle. A respirator is strongly recommended during this procedure due to the potential release of volatilized lead and organic compounds (HUD, 1991; NIOSH, 1992; Labor, 1993).

B.3.2 Scientific Evidence on Handscraping with Heat Gun

Despite softening the paint, this procedure had mixed success in abating lead-based paint from floors and windows in the HUD Demonstration. Residences abated by hand-scraping with heat gun failed the initial clearance test 28.8, 24.4, and 44.5 percent of the time for floors, window sills, and window wells, respectively. In comparison, residences abated by replacement of building components coated with lead-based paint failed the initial clearance test 12.5, 7.4, and 21.0 percent of the time for floors, window sills, and window wells (HUD, 1991).

Although a 700°F temperature restriction was placed on heat guns used in the HUD Demonstration, PAEs exceeded the OSHA action limit in 17.5 percent of 360 samples collected by HUD contractors when a heat gun was in use. In addition, 6 of 10 PAE samples collected by National Institute for Occupational Safety and Health (NIOSH) investigators during interior heat gun work exceeded the OSHA PEL. The PAE samples collected by HUD contractors and NIOSH investigators tended to be over short time periods, however it was assumed that the sampling periods were representative of full shift exposure (NIOSH, 1992; HUD,1991).

A slight (though not statistically significant) increase in mean PbB was observed within one month of abatement for 19 children living in 18 Baltimore homes abated by this method, even with thorough (wet cleaning with high-phosphate detergent together with dry vacuuming with standard shop vacuums) cleanup following the abatements. Post-abatement dust-lead levels in these homes showed decreases in window sill and window well dust-lead levels, but increased levels on floors. By six months post-abatement, dust-lead levels were similar to, or greater than, pre-abatement levels (Farfel and Chisolm, 1990).

PAEs during heat gun use were reported for 380 samples, averaging 26 $\mu g/m^3$ per hour over 8 hours with individual sample exposures ranging from 0.4 $\mu g/m^3$ to 916 $\mu g/m^3$ (Labor, 1993).

B.4 TORCH METHODS

B.4.1 Description of Torch Methods

Similar to the heat gun method, a propane torch can be used to soften lead containing paint, before removing it by hand-scraping. Alternatively, the torch can be used to burn the paint, with residue removed by sanding. As with heat guns, high levels of lead and organic compounds can be volatilized. Indeed, since there is less control over temperature, volatilized lead levels are likely to be greater.

B.4.2 Scientific Evidence on Torch Methods

In the Boston Retrospective study, an average increase of 35.7 $\mu g/dL$ in PbB during abatement, compared with pre-abatement PbB, was reported for 4 children whose homes were abated using torches to soften lead containing paint prior to scraping (Amitai, et al, 1991).

In 53 Baltimore homes, traditional methods of abatement (usually entailing open-flame burning and sanding) resulted in 3 to 6 fold increases in lead-contaminated house dust over pre-abatement levels, with 10 to 100 fold increases at abated sites. By 6 months post-abatement dust-lead levels were similar to, or greater than, pre-abatement levels. The mean PbB of 27 children living in these homes increased by 6.8 $\mu g/dL$ within one month of abatement (Farfel and Chisolm, 1990).

In the same study, a subset of 19 dwellings were monitored more frequently. Downward trends in lead dust on floors and window sills were observed following abatement. These trends were greatest during the first month. By 3 months post-abatement, dust-lead levels were similar to the levels that would be observed in these homes at 6 months post-abatement. At 6 months post-abatement, dust-lead levels in these homes were similar to the levels observed in all study homes (Farfel and Chisolm, 1990).

A Baltimore study of 184 children who received inpatient chelation therapy found that PbB increased during the first 3 months after discharge and remained stable for the remainder of the 12 month study period. Discharge was keyed to abatement of the dwelling, or relocation of the family to lead-free public housing. Study homes were usually abated by using a gas torch to soften paint so that it could be scraped off, followed by sanding down to bare wood. Children discharged to abated homes, or who routinely visited unabated lead containing homes or abated homes, had significantly higher PbB than children residing exclusively in lead-free public housing (38.5 vs. 28.8 μg/dL at 3 months). In addition, PbB increased by about 10 μg/dL within about 3 months in a small number of children who moved from lead-free public housing to abated homes, and decreased similarly in those who moved from abated homes to lead-free public housing (Chisolm, et al, 1985).

B.5 DISCUSSION

The studied abatements often combined methods which can produce large amounts of lead contaminated dust or volatilized lead with poor cleanup. Though improved cleanup may mitigate the effects of increased dust-lead levels, it is not a complete solution. Children and workers may be exposed during the deleading process, prior to cleanup. Also, improved cleanup was not helpful in Baltimore (Farfel and Chisolm, 1990) or Massachusetts, where more stringent abatement regulations were enacted in 1988 (Swindell, et al, 1994). Indeed, it may be impossible to completely remove leaded dust from carpets, as demonstrated in Cincinnati (EPA, 1993).

The abatement methods under consideration have been reviewed by HUD and the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA). Although their focus was on worker protection rather than reducing childhood lead exposure, the recommendations of these agencies regarding the abatement methods under consideration may be of interest. Table 1 summarizes the recommendations in "Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing" (HUD, 1994) and "Lead Exposure in Construction; Interim Final Rule" (Labor, 1993) regarding sanding, dry scraping, hand scraping with heatgun, and torch methods. Also, the results of the U.S. Environmental Protection Agency Renovation and Remodelling Study will be available soon. The focus of this study is on worker protection as well, however, the additional information on personal air exposure to airborne lead during paint removal by sanding and dry scraping which will be provided may be of interest.

Although a lengthy discussion of alternative methods is beyond the scope of this document, it should be noted that a variety of intervention strategies have been studied. In addition to sanding and hand scraping with a heat gun, the HUD Demonstration tested abatement strategies of chemical removal of lead-based paint, encapsulation, enclosure, and replacement of building components coated with lead-based paint. Most of these alternative methods produced less hazardous waste and were less likely to produce high levels of airborne lead. In addition, abated residences were more likely to pass initial clearance tests (HUD, 1991). In Boston, significant declines in PbB levels during abatement, compared with pre-abatement PbB, were observed in 12 children whose homes were abated by replacing or permanently covering painted surfaces (Amitai, et al. 1991). Alternative intervention strategies including in-place management, dust control, and educational interventions have been used effectively, as well as these alternative abatement strategies. Many of these methods have been summarized and their effectiveness reviewed (Battelle, 1994a; Battelle, 1994b; Burgoon, et al, 1993).

Table B-1. Summary of HUD and OSHA Recommendations Regarding Sanding, Dry Scraping, Hand Scraping with Heat Gun, and Torch Abatement Methods.

Abatement Method	HUD Guidelines	OSHA Rule[a]
Sanding		
-Manual	Not Mentioned	Halfmask APR
-Power[b], with HEPA Dust Collection	Recommended	Halfmask APR
-Power[b], no HEPA Dust Collection	Banned	Powered[c] APR
Dry Scraping	Not Recommended[d]	Halfmask APR
Hand Scraping with Heat Gun		
- Below 1100°F	Recommended	Halfmask APR
- Above 1100°F	Banned	Halfmask APR
Torch Methods	Banned	Not Mentioned

[a] Respirators are required unless air sampling at the specific job site indicates lower lead levels than usual. Halfmask air purifying respirators (APR) should have a protection factor of 10. Powered APRs should have a protection factor of at least 25, with higher protection factors required for some tasks.

[b] This includes power grinders, brushes, needle guns, sanders, and abrasive blasting devices.

[c] Higher protection factor required for abrasive blasting devices than for other power tools.

[d] Dry scraping is not recommended by HUD, nor is it banned. Wet scraping is preferred over dry scraping, however, when wet scraping is not safe or practical, e.g. near electrical outlets, dry scraping is permissible.