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REVIEW OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS: UPDATED EDITION

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for

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FURTHER INFORMATION

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EXECUTIVE SUMMARY

INTRODUCTION

This report updates the U.S. Environmental Protection Agency technical report, *Review of Studies Addressing Lead Abatement Effectiveness* (EPA 747-R-95-006, July 1995), which summarized the results of 16 lead hazard intervention studies. The original edition presented results indicating that lead hazard interventions could reduce the blood-lead concentrations of exposed children. However, only a limited variety of intervention strategies were documented in the available literature and a number of data “gaps” were identified. Strategies seeking to prevent a child from being exposed to the lead in her or his surrounding environment continue to be studied and their resulting effectiveness is being reported in the scientific literature. This updated report summarizes 19 additional studies available in the scientific literature. In deriving the conclusions and recommendations cited in this updated report, all the available published data were considered. The combined review presented herein was intended to aid in assessing the potential benefits of rule-making under the Toxic Substances Control Act (TSCA), Title IV, and, particularly, the §403 rule on lead hazards in paint, dust, and soil.

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. The literature on lead hazard intervention efficacy focuses on impeding the hand-to-mouth pathway of childhood exposure to environmental lead sources by either abatement or interim controls. Abatement encompasses interventions that remove or permanently cover lead-based paint or soil that contains lead. In contrast, interim controls may include paint stabilization (removal of only deteriorated lead-based paint) or abatement of lead-containing dust, but the lead source is not removed (e.g., intact lead-based paint or soil with elevated lead levels). Interim controls are attractive in some cases because of their low up-front cost relative to many abatement techniques. This report also reviews the literature on educational interventions.

Whereas many of the studies summarized in the original technical report examined the effectiveness of abating lead-based paint, the new studies tended to examine less extensive intervention strategies utilizing paint stabilization or dust control efforts. Additional soil abatement studies and educational studies are also now available. As a result, some of the data gaps identified in the earlier report have been at least partially filled. The new studies also improve our understanding of how the many strategies may be used together in a comprehensive lead hazard reduction program.

MAJOR FINDINGS

- *There is a growing body of evidence that lead hazard interventions can reduce exposed children's blood-lead concentrations and dust-lead levels in homes.*

- *In many ways, the available data remain limited. Although there are now a number of studies on the subject, few are large enough to provide substantial evidence of an intervention's effectiveness. No single intervention strategy stands out as markedly superior. Given the limited data available, this does not imply that these strategies are interchangeable. Rather, the comparability suggests that other relevant factors should serve as the determinants of the strategy suitable for a given situation.*

- *Some approaches used in the past were hazardous and should be avoided. Methods that have been clearly shown to be hazardous, such as open flame burning and types of mechanical dry sanding, have been banned for lead abatement by EPA under TSCA §402 and by some local governments. Moreover, certain other practices may be ineffective, suggesting that care should be taken in choice of intervention strategy.*

- *The magnitude of the decline in an exposed child's blood-lead concentration observed following an intervention is a function of the child's pre-intervention blood-lead concentration. Greater declines are reported for children with higher initial blood-lead concentrations. An intervention strategy reported as effective in reducing the blood-lead concentrations of children above, say, 20 µg/dL, may not be as successful among children with lower blood-lead concentrations.*

- *None of the intervention strategies studied to date have consistently brought blood-lead concentrations below the level of concern (<10 µg/dL).*

- *It is possible that primary prevention, that is, preventing lead exposure before it occurs in the first place, may be somewhat more successful than secondary prevention. In addition, community wide efforts to reduce lead exposure might be considerably more effective than efforts in individual homes in preventing elevated blood-lead levels.*

- *Four critical data gaps remain: 1) no data exist regarding primary prevention effectiveness rather than secondary; 2) little documentation is available regarding the long-term effectiveness (i.e., greater than one year) of lead hazard intervention; 3) some promising intervention strategies, such as soil cover, encapsulation and enclosure of lead-based paint, have received relatively little study; and 4) the reasons* *for blood-lead levels not being brought below 10 µg/dL are not well understood. However, some research is being done to address these critical data gaps.*

DISCUSSION

Since the publication of the earlier review, a number of additional intervention strategies have been studied and documented in the scientific literature. Some of these studies have helped to fill some of the research "gaps" noted in the earlier review. Others, however, have re-emphasized the need for investigation of certain remaining issues and prompted new questions. The research surrounding the effectiveness of lead hazard intervention strategies remains active and large data gaps remain.

Though this report and the earlier edition summarize studies of the effectiveness of a range of environmental and behavioral intervention strategies on their ability to reduce childhood lead exposure, efficacy is measured only among already exposed children. The reported efficacy, then, is termed "secondary prevention effectiveness." Though most certainly noteworthy, secondary prevention is not representative of the effectiveness being sought from the promulgation of lead hazard control regulations such as the TSCA §403 standards for lead in dust, soil, and paint. The §403 standards are primarily intended to prevent childhood lead exposure before it occurs and, therefore, their efficacy will be assessed by measures of what is termed "primary prevention effectiveness." In the context of this report, primary prevention effectiveness is the prevention of elevations in blood-lead concentrations associated with the conduct of the intervention before a child has an elevated blood-lead level. Perhaps the most critical data gap, therefore, is the lack of published results documenting primary prevention efficacy following an intervention. However, primary prevention can be assumed to be at least as effective as secondary prevention and may be considerably more effective.

When considering the effectiveness of an intervention, it is important to recognize that childhood lead exposure stems from a number of media (e.g., interior paint, exterior paint, including paint on windows, soil, interior house dust, exterior dust) across a range of environments (e.g., child's residence, school, playground, friend's residence). Children may derive their exposure primarily from a single residential source, which may be successfully targeted by an intervention. Alternatively, incremental exposures to several lesser sources may be sufficient to cause moderately elevated blood-lead levels. 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 such a decline is even physiologically possible). If other sources of lead remain unaffected by the intervention, lead exposure may continue and the child's blood-lead concentration may remain at least partially elevated. Caution should accompany any effort to extend results observed among children with more elevated blood-lead concentrations to those with lower levels.

Declines in blood-lead concentration on the order of 25% were reported for extensive, carefully managed projects which abated sources of lead, as well as for interim controls. A range of lead hazard intervention strategies were documented to have a statistically significant positive "effect" on the blood-lead concentrations of exposed children in comparison to a control group. Lead-based paint abatement, dust lead intervention, soil lead intervention, and educational intervention were documented to have at least the *potential* for producing significantly greater declines in blood-lead concentration among children benefitting from the intervention than among a control population of children. The efficacy of these interventions is characterized as "potential" because not every case of the type of intervention strategy was effective. The specific details of the effective intervention strategies were critical. In addition, none of the studied intervention strategies was consistently effective in reducing children's blood-lead concentrations to a level below the level of concern (< 10 µg/dL, as recommended by CDC, 1997).

It should be noted, finally, that the comparability in effectiveness of a range of intervention strategies does not imply these strategies are interchangeable. Instead, it suggests that other factors should determine which strategy is suitable for a given situation. These factors include the strategy's cost (both up-front and long-term), its viability, the type of lead exposure facing the child, and the expected long-term efficacy.

1.0 INTRODUCTION TO THE PROBLEM

The Environmental Protection Agency (EPA) technical report, "Review of Studies Addressing Lead Abatement Effectiveness" (EPA 747-R-95-006), published in July 1995, summarized the results of 16 lead hazard intervention studies. That report was a comprehensive review of the scientific literature available at that time regarding the effectiveness of lead hazard intervention. This report updates that literature review and summarizes 19 additional studies that add to the body of scientific literature on this topic. This updated review is intended to aid in assessing the potential benefits of rulemaking under Title IV of the Toxic Substances Control Act (TSCA), specifically the TSCA §403 standards for lead in dust, soil, and paint. As in the original edition, 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 and children regarding the dangers of a young child's hand-to-mouth activity. Intervention strategies employed by specific studies may combine activities that attempt to remove or isolate a source of lead exposure through abatement or interim controls with activities that attempt to reduce a child's lead exposure by modifying parental or child behavior patterns. In this report, abatement encompasses interventions that are intended to remove or permanently cover lead-based paint or soil that contains lead. While the U.S. Department of Housing and Urban Development (HUD, 1995) has adopted a stricter definition, many studies do not provide enough information to determine whether the studied abatement meets that standard. Interventions that employ interim controls may include paint stabilization (removal of only deteriorated lead-based paint) or abatement of lead-containing dust, when the lead source (e.g., intact lead-based paint or soil with elevated lead levels) is not removed.

Substantial effort has been focused on the development and demonstration of methods for reducing childhood lead exposure and body-lead burden by applying interventions which seek to address environmental lead hazards. It is expected that these interventions will prevent or reduce (at least temporarily) further exposure and produce positive health outcomes. The extent to which recently published scientific literature supports this expectation is characterized in this report. Information on the effectiveness of lead hazard intervention in reducing childhood lead exposure was compiled in the earlier technical report (USEPA, 1995a) and in other reports covering much of the same material (Burgoon et al., 1995; Staes and Rhinehart, 1995). For reference, substantial portions of the earlier U.S. EPA technical report are provided in Appendix C, with minor revisions to improve format or to incorporate newly available information. The studies included in these reports address the efficacy of specific 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. That is, secondary prevention is defined as preventing future lead exposure in a child who has already been exposed and has an elevated blood-lead level. Primary prevention, on the other hand, is defined as preventing lead exposure before the child has been adversely exposed to lead, that is, before the child has an elevated blood-lead level. The literature currently documents no primary prevention studies, though at least one such study is under way.

In reviewing these studies, it is important to consider epidemiologic issues that may affect the interpretation of reported results. These issues include the method of selecting subjects, the method of assigning subjects to treatment groups, the presence of a control group, seasonal trends in blood-lead concentrations, and age-related behavior patterns that are associated with lead exposure. Practical constraints may dictate how a study is designed and how well the investigators are able to control these factors. For example, most studies enroll children with at least moderately elevated blood-lead levels. Thus, the study of primary prevention effectiveness is difficult. In some cases, children cannot be randomly allocated to treatment groups. For ethical reasons, children with greater elevations are automatically assigned more extensive interventions. In addition, controlling for factors such as seasonal and age-related trends can be incompatible goals. The optimal follow-up period for minimizing seasonal variation is one year. Yet, in that time, behavioral changes are likely to occur in young children, which can affect lead exposure. For this reason, it is best to include a comparable control population in the study. However, it is not always possible to include a control group, particularly when the target population is children with blood-lead concentrations above 20 μg/dL. Finally, many factors are beyond the control of the investigators. These include families that move, problems in gaining the consent of both tenants and landlords, and local regulations that limit options for studied interventions and group assignments. These factors are inherent difficulties in the study of lead hazard intervention effectiveness.

The earlier edition of this report noted evidence that indicated lead hazard interventions could effectively reduce the blood-lead concentrations of exposed children. However, only a limited variety of intervention strategies were documented and a number of data "gaps" were identified in the body of research (e.g., long-term effectiveness and efficacy among children with blood-lead concentrations less than 20 µg/dL). It was hoped that additional research might now be available to address these issues. This updated edition was initiated to consider the latest research regarding intervention effectiveness. This report summarizes both the newer and previously reported studies related to intervention effectiveness.

1.1 ORGANIZATION OF THE REPORT

Following in Section 2 is a discussion of the measures for assessing the efficacy of an intervention strategy, primary versus secondary prevention, and source apportionment. Section 3 is a review of the scientific evidence. Section 3.1 summarizes the results of the original 16 studies that were presented in the 1995 technical report, including recent information from these studies. In Section 3.2, 19 additional studies are summarized that have examined the extent to which lead hazard intervention results in reduced lead exposure and lower blood-lead levels in children. A summary of the previous and additional scientific evidence is presented in Section 4. This summary focuses on how the new information adds to the body of literature reviewed in the technical report. Section 5 presents the conclusions and recommendations derived from the review. Included at the end of the report are references, an Appendix A which contains abstracts of the 19 studies, and an Appendix B which contains tables that summarize the blood-lead and environmental-lead levels over all studies. Two additional appendices contain updated portions of the 1995 technical report. Appendix C contains the 16 individual study summaries from Chapter 3, as well as each study's abstract from Appendix A of the 1995 edition. Appendix D reproduces Appendix B of the 1995 edition, a review of abatement methods associated with temporary increases in blood-lead levels. Appendix E contains a draft report that reviews published information on post-intervention wipe dust-lead loadings on floors and window sills. This report was prepared to support efforts to re-evaluate and refine the §403 risk analysis assumptions on post-intervention wipe dust-lead loadings. The material in this appendix should be considered a preliminary, informational draft, unlike the rest of the report, which received extensive review.

1.2 PEER REVIEW

This report was reviewed independently by members of a peer review panel. In general, the peer reviewers concluded that the report was comprehensive, accurate, and relevant to current policy concerns. However, the peer reviewers did provide useful suggestions for revisions, as well as important issues to consider when interpreting the results. Comments that were either important for interpreting the results or resulted in significant modifications to the report are discussed below.

Many of the comments requested additional detail, clarification of the methods used, improved figures, or additional interpretation of results reported by specific studies. To the extent possible, we added the requested information. The largest item was probably the revision of the summary of the HUD Abatement Grant program. The original review was based on data reported in the Fourth Interim Report on that study, dated March 1997. The Fifth Interim Report came out as we were completing the peer review draft of this report. The additional results were incorporated in the report. In addition, one reviewer pointed out that we had not used the EPA integrated analysis (USEPA, 1996e) in our summary of the "Three Cities" studies. Since these studies are summarized separately in Section 3.2 and Appendix A, we added a brief summary of the conclusions of that report in Section 4.1, where the studies are summarized together.

Several comments pointed out discrepancies in terminology between that used by HUD and that used in this report: (1) we do not use HUD's definition of abatement as a treatment lasting 10-20 years; (2) lead-based paint inspections reported by specific studies may not conform to HUD *Guidelines* (HUD, 1995) or may not have been performed by certified inspectors; and (3) the clearance testing criteria used in specific studies may not be consistent with HUD *Guidelines* recommendations. In general, we do not apply the HUD standards, as very few of the intervention studies applied the HUD criteria. Even the most detailed reports fail to provide enough information to determine whether the intervention would meet these standards. Although we could not fully address these concerns, we felt it important to point out the discrepancy here, as well as in the report.

One reviewer did not agree with our use of declines in blood-lead concentration as the primary measure of intervention effectiveness and recommended we put more emphasis on changes in dust-lead levels. Although we disagreed with the comment, we did review the information presented and provided additional dust-lead results for some studies. A draft report on post-intervention dust-lead loadings on floors and window sills was added in Appendix E in response to this comment. We also revised Section 2.1 to better present our reasoning for selecting blood-lead concentrations as our primary measure of effectiveness.

One reviewer pointed out that comparisons of dust-lead loadings between studies can be difficult when different sampling methods are used and suggested that we recommend future researchers use wipe sampling as at least one method. In response to this comment, we added material to Section 5.4 making this recommendation and others that would improve comparability of results across intervention studies.

Several comments pointed out the importance of control populations in assessing the effect of an intervention in the presence of confounding factors, such as age and seasonal trends in blood-lead levels. In response to these comments, we revised the discussion defining the "effect" of an intervention as the change in blood-lead concentration beyond that observed in comparison to a comparable control population (Section 2.1). We also modified the text to reinforce the definition, wherever the term is used. In addition, we were careful to point out where control populations were used and where they were not in the individual study summaries, Figure 5-1, and Table 4-1.

EPA has established a public record for the peer review under Administrative Record 151. The record is available in the TSCA Nonconfidential Information Center, which is open from noon to 4 PM Monday through Friday, except legal holidays. The TSCA Nonconfidential Information Center is located in Room NE-B607, Northeast Mall, 401 M Street SW, Washington, D.C.

2.0 ASSESSING INTERVENTION EFFICACY

2.1 MEASURES OF INTERVENTION EFFICACY

When reviewing studies assessing the effectiveness of lead hazard intervention, there are a variety of environmental, behavioral, and/or physiological parameters that have been used to quantify efficacy. The goal when summarizing these studies is to utilize a measure which adequately reflects the potential benefit or detriment resulting from the intervention. Interventions are undertaken to reduce or eliminate environmental lead exposure, with the aim of positively impacting the health of resident (either current or future) children or adults. Young children (i.e., under six years of age) are the population most at risk from lead exposure and, as a result, are the group expected to benefit from most of the intervention procedures commonly employed. A suitable measure of efficacy, therefore, should reflect the impact of the intervention on the health of affected children. For reasons discussed in this section, we have chosen to use the change in blood-lead concentration of resident children as the primary measure of intervention effectiveness in this report.

It would be ideal to precisely measure particular health outcomes stemming from lead exposure, such as decreased learning deficits or increased motor coordination, among children benefitting from an intervention. In fact, one study of moderately exposed children (Ruff et al., 1993) reported 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. More importantly, many of the health benefits are subtle and, as such, are complicated and costly to measure and verify.

Recognizing lead-related health outcomes is particularly difficult if the child was not exhibiting symptoms of adverse lead exposure before the intervention was initiated. In such instances, intervention efficacy may have to be assessed using tests of learning aptitude or intelligence quotient (IQ). This approach was utilized in the aforementioned study of cognitive function (Ruff et al., 1993). The small differences usually recorded 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 was seen in the earlier summary report and will be seen in the reviews in Section 3.0, none of the identified studies (save the Ruff et al. study) measured specific health outcomes associated with their interventional practice.

Consistent with these limitations, measures of body burden such as blood-lead concentration usually are utilized as biomarkers of lead exposure and intervention effectiveness. Such measures indicate the extent to which the intervention impacts affected children and serve as biomarkers of lead exposure. There is extensive evidence that measures of body-lead burden are associated with lead levels in environmental media (USEPA, 1986; CDC, 1991, 1997). 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. More importantly, the accuracy and representativeness of bone-lead concentrations measured externally by an x-ray fluorescence (XRF) instrument has been questioned by many researchers (Wedeen, 1988). Blood-lead and EP levels can be more readily measured, but reflect a varying mixture of long-term and more recent exposure (ATSDR, 1993; Janin et al., 1985; Hernberg et al., 1970). Despite the complex interaction of prior and current exposure evident in measured blood-lead concentrations, they are still the measure of choice for most studies of intervention effectiveness.

There is an extensive body of literature relating blood-lead concentrations to specific health outcomes stemming from lead exposure, though much of it examined children with levels of exposure usually indicative of lead poisoning (USEPA, 1986). More recent evidence has been reported suggesting that even low levels of exposure, as measured via blood-lead levels, are associated with learning deficits (CDC, 1991, 1997; Goyer, 1993; Schwartz, 1994). The Centers for Disease Control and Prevention (CDC) state that, “Blood lead levels (BLLs) as low as 10 μg/dL are associated with harmful effects on children’s ability to learn” (CDC, 1997). Though this documented association 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. Reductions in blood-lead concentration, therefore, can be used to measure 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 change due to factors unrelated to the intervention, such as seasonal variation, the growth of the child, behavioral changes stemming from an increased awareness of the health risk from lead, or simply random variation. In some studies, these decreases unrelated to the intervention are characterized by examining a comparable control population. For these studies, we are able to estimate the “effect” of an intervention, adjusting for the blood-lead concentration change observed in the control population. As a number of the identified studies did not examine a control population, we also report the blood-lead concentration reductions of the study population as the “efficacy” or “effectiveness” of the strategy employed.

When it is impractical or inappropriate to measure blood-lead concentrations, changes in the lead levels of surrounding environmental media can provide valuable information. Such measures cannot directly demonstrate the intervention’s impact on affected children. Environmental measures can, however, be used to evaluate and confirm the effectiveness of a particular procedure in reducing or eliminating a targeted lead hazard. Environmental measures are 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 is reported. However, the primary measure used in this report, as was the case in the original report, is change in the blood-lead concentrations of exposed children. This measure of body-lead burden is commonly employed when assessing lead exposure and was collected in a majority of the identified studies.

2.2 PRIMARY VERSUS SECONDARY PREVENTION EFFICACY

Though this report and the earlier review summarize studies of the effectiveness of a range of behavioral and environmental intervention strategies on their ability to reduce childhood lead exposure, efficacy is measured only among already exposed children. The reported efficacy, then, is termed “secondary prevention effectiveness.” Though most certainly noteworthy, secondary prevention intervention effectiveness is not representative of the effectiveness being sought from the promulgation of lead hazard control regulations such as TSCA Title IV. The Title IV (§403) standards for lead in dust, soil, and paint are primarily intended to prevent childhood lead exposure before it occurs and, therefore, their efficacy will be assessed by measures of what is termed, "primary prevention effectiveness." In the context of this report, primary prevention effectiveness is the prevention of elevations in blood-lead concentrations stemming from conduct of the intervention before a child has an elevated blood-lead concentration.

The absence of studies documenting the primary prevention effectiveness of an intervention strategy is not surprising, since such a study is inherently difficult. How does one document the increase in blood-lead concentrations prevented by an intervention? One approach reportedly being utilized in a CDC study is to contrast the blood-lead concentrations of children exposed to a lead hazard with that of their younger siblings (presumably not yet exposed to the same hazard) benefitting from the intervention conducted once the hazard was identified. Such a difference assumes no other differences (e.g., increased awareness of the hazard from environmental lead or improved house cleaning practices) between the environments and behaviors of the contrasted children. Given the challenges inherent to studying primary prevention, it is likely only a few such studies will ever be available.

Secondary prevention efficacy results are not necessarily representative of those expected from primary prevention because, as was noted earlier, lead present in blood is a combination of current environmental exposure and internal sources of lead. A significant internal source of lead is bone tissue. After prolonged exposure to lead, bone tissue retains much more lead than the other body tissues (Barry and Mossman, 1970; Barry, 1975; Barry, 1981; Schroeder and Tipton, 1968; and Leggett et al., 1982). Nordberg et al. (1991) suggest that bone can become an internal source of lead during periods of reduced external exposure to lead; (see also Hyrhorczuk et al., 1985; Rabinowitz et al., 1976; and Rabinowitz, 1991). Any reported declines in blood-lead concentration among already exposed children, therefore, may underestimate the primary prevention effectiveness of the associated intervention strategy.

Given these issues one obvious question is whether secondary prevention results might be "translated" into primary prevention results. Unfortunately, there is limited empirical evidence regarding the extent to which bone-lead stores are able to keep blood-lead levels elevated following an intervention, especially concerning children. One study (Markowitz et al., 1993) measured bone-lead levels in children before and after an intervention, but found no significant decline in the levels over a period of six weeks. Despite the lack of studies concerning children, Nordberg et al. (1991) claim that "skeletal turnover is highest among children under 10 years of age." Several studies have been conducted to study bone-lead mobilization in adults (Wrenn et al., 1972; Cohen et al., 1973; Rabinowitz et al., 1973; Batschelet et al., 1979; Heard and Chamberlain, 1984; Marcus, 1985; Christoffersson et al., 1986; Cristy et al., 1986; Schutz et al., 1987; Bert et al., 1989; Nilsson et al., 1991; and Gulson et al., 1995). For example, Gulson et al. (1995) show that 45% to 70% of lead in the blood of adult women comes from long-term tissue stores, primarily the bone tissue. A similar result was observed in another study on five adult subjects undergoing knee and hip replacement (Smith et al., 1996).

If, despite the limited data, the contribution of mobilized bone-lead stores can be characterized, it would be possible to translate the documented secondary prevention results into estimated primary prevention results. An effort at such a translation was presented in the sensitivity analysis of the TSCA §403 Risk Assessment report (USEPA, 1998b). The approach was based on a bone-lead mobilization model developed (Rust et al., 1999) to estimate the degree to which bone-lead stores could mask the full effectiveness of an intervention by mobilizing into the child's blood. Table 2-1 was the end result of this effort. In particular, Table 2-1 presents the estimated primary prevention effectiveness (with the standard error of the estimate noted in parentheses) associated with an intervention strategy documented to have a specific secondary prevention effectiveness when measured a specific period of time following the intervention. For example, from Table 2-1, if a 25% decline in blood-lead concentration is reported for exposed two-year-old children 12 months following a given secondary prevention intervention, the estimated primary prevention decline would be 33%. The estimated standard error for this estimate would be 8% as shown in the parentheses. Using Table 2-1, it is possible to estimate the primary prevention effectiveness associated with the intervention strategies documented in the scientific literature given their reported secondary prevention effectiveness (if such effectiveness is reported in terms of reduced blood-lead concentrations).

Empty cells in Table 2-1 indicate that those scenarios cannot possibly occur based on the bone-lead mobilization model. For example, for a 7-year old, the impact of mobilized bone-lead

Table 2-1. Maximum Efficacy (%) of Primary Prevention For Blood-Lead Levels Observed at 25%, 50%, and 75% of Pre-Intervention Levels at 6, 12, 18, and 24 Months (Estimated Standard Errors Shown in Parentheses)

Observed Efficacy of Secondary Prevention[a]	Child's Age at Time of Intervention (years)	Length of Time[b] (months)			
		6	12	18	24
25%	1	39 (16)	30 (5)	28 (3)	27 (2)
	2	47 (18)	33 (8)	30 (4)	28 (3)
	3	56 (21)	36 (14)	31 (7)	29 (4)
	4	67 (25)	41 (19)	34 (10)	31 (6)
	5	79 (27)	47 (19)	37 (14)	33 (8)
	6	91 (32)	53 (21)	40 (19)	35 (12)
	7		59 (22)	44 (19)	37 (15)
50%	1	78 (32)	60 (9)	56 (5)	55 (4)
	2	94 (36)	65 (16)	59 (8)	56 (6)
	3		73 (27)	63 (13)	59 (8)
	4		83 (37)	68 (21)	62 (13)
	5		93 (38)	73 (29)	66 (17)
	6			81 (37)	70 (24)
	7			89 (37)	75 (31)
75%	1		90 (14)	84 (8)	82 (5)
	2		98 (25)	89 (13)	85 (9)
	3			94 (20)	88 (13)
	4				93 (19)
	5				98 (25)
	6				
	7				

Note: An empty cell means that the scenario is not possible according to model predictions.
(a) This is equivalent to the observed percent decline in an exposed child's blood-lead levels at a specified time following the intervention.
(b) This is equivalent to the length of time following the intervention when the decline was observed.

stores would be estimated to preclude a 25% decline in blood-lead concentration at 6 months, even for a 100% effective intervention. Estimates of primary prevention efficacy under these "impossible" scenarios were not meaningful and, therefore, were not presented.

Consistent with the limited data available on bone-lead mobilization, the standard errors reported parenthetically in Table 2-1 are quite large. This considerable degree of uncertainty should be considered when interpreting any "translated" primary prevention efficacies derived from published secondary prevention effectiveness results.

2.3 SOURCE APPORTIONMENT

When considering the effectiveness of an intervention strategy in reducing a child's blood-lead concentration, it is important to recognize the many different avenues by which a child may be exposed to lead. An intervention will be most efficacious if it targets those sources and pathways of lead exposure most responsible for the child's elevated lead burden. 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 his/her 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. The pathways of the exposure are indicated by directional arrows. 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 may vary from child to child. One child may play in dust containing high lead levels at her residence and soil containing high lead levels at a day care center. A second child may obtain his exposure largely from lead-contaminated dust at a friend's house. As a result, an abatement can only reduce a child's lead exposure to a degree consistent with the extent to which the targeted source of exposure represents a hazard to the child. For example, 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%.

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 lead-based paint, industrial emissions, gasoline, and solder, although the lead arising from these sources has been reduced markedly during the time span of the reviewed studies. 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 lead-containing dust within a residence will potentially result in only transient

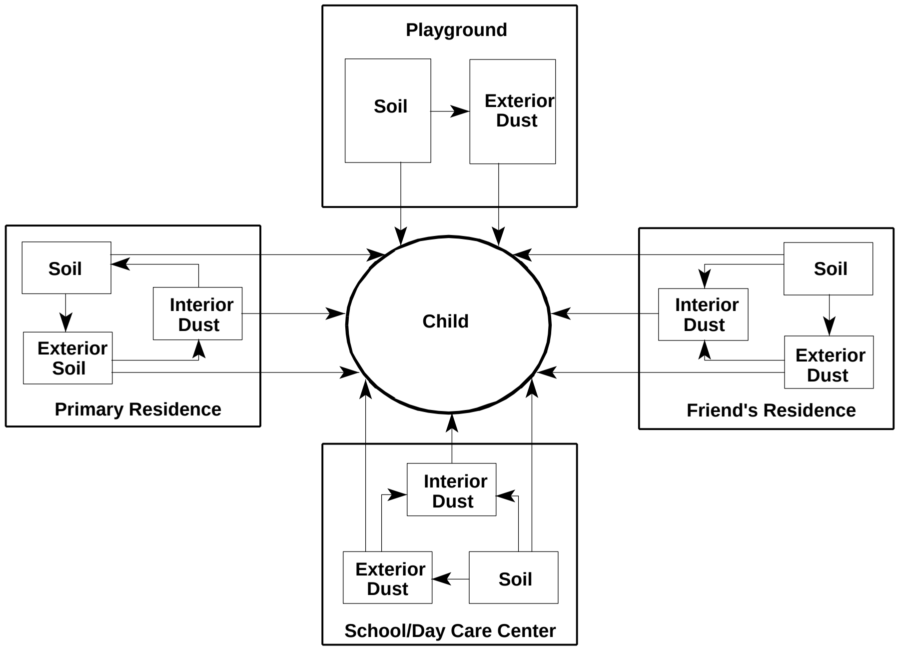


Figure 2-1. Selected Micro-Environments and Lead Hazards to Which a Child May Potentially Be Exposed.

declines in the blood-lead levels of resident children. If the unabated source of lead (e.g., deteriorating lead-based paint) recontaminates the dust, the child's blood-lead concentration may rapidly return to its earlier 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). The effectiveness of the intervention would then be delayed depending upon the rate at which the contamination of environmental media dissipates.

Each of the interventions that are discussed in this report can be viewed as an attempt to reduce or eliminate one or more of a child's lead exposure pathways. Within a micro-environment, the intervention should be targeted at those exposure pathways that have the greatest effect on the health of the child. The success of an intervention is ultimately determined by the magnitude of the reduction in the body-lead burden of a child. Potentially, an intervention could 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.

3.0 REVIEW OF SCIENTIFIC EVIDENCE

Strategies seeking to prevent a child from being exposed to the lead in her or his surrounding environment continue to be studied and their resulting effectiveness reported in the scientific literature. The original edition of this review contained a number of studies utilizing relatively extensive intervention strategies such as lead-based paint abatement and lead-contaminated soil abatement. Since the publication of the original edition, additional lead hazard intervention studies have been reported. Many of these new studies examine less extensive interventions utilizing educational strategies, dust control efforts, paint stabilizations, and other interim control measures. As a result, a number of the data gaps identified in the earlier report have been at least partially filled. More importantly, a more robust picture of the relative efficacies of paint, soil, dust and educational interventions is now available, as well as an enhanced understanding of how the many strategies fit together in a comprehensive lead hazard reduction program. However, many fundamental questions remain, some of which are being examined by current studies.

Section 3.1 is a slightly updated summary of the original edition of this report and the studies documented therein. This summary facilitates consideration of the recently published studies. Section 3.2 provides a summary of each of the new studies, arranged in chronological order. Each study summary reviews the study's objective, design, results, and derived conclusions. A more detailed abstract of each study is available in Appendix A. The corresponding summaries and abstracts from the prior report are reproduced (with minor updates) in Appendix C. Summary tables which had been included in the prior report have been expanded to include the new studies. The expanded tables are presented in Section 4.0 and Appendix B.

3.1 SUMMARY OF PRIOR SCIENTIFIC EVIDENCE

The literature on lead hazard intervention efficacy available at the time of the original review 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, 1997; ATSDR, 1988; USEPA, 1998b). The pathway may be disrupted by a variety of means including the abatement of lead-based paint, dust-lead level reduction procedures, and lead-contaminated soil abatement.

The literature was limited in its scope. It only covered some of the many abatement types and methods used in practice. However, the studies suggest that both abatement and interim control 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, and yet there are disadvantages to both. For example, interim controls require sustained effort to maintain their effectiveness. Abatement methods, in turn, sometimes have an accompanying risk of at least short-term elevation of residents' blood-lead levels that must be factored into any summary of intervention effectiveness. The methods responsible for the elevated blood-lead levels were identified and summarized in Appendix B of the original edition, which has been reproduced in Appendix D of this updated edition. The hazardous methods identified in this report are now prohibited under the TSCA §402 abatement practices standards and by some local laws as well.

The results of 10 paint abatement studies were examined. The literature suggested that the efficacy of these methods depended 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 abatement methods 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 Abatement Demonstration (HUD

Demo) study (HUD, 1991, 1990) also suggest that clearance standards may be easier to meet via encapsulation and enclosure methods than via removal methods. The Denver Comprehensive Abatement Performance (CAP) study (USEPA 1996a, 1996b) indicated that long-term interior dust-lead levels were somewhat higher, though not statistically higher, in encapsulation/enclosure homes than in removal homes. However, 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 methods resulted in 18- to 24-month follow-up dust-lead levels below HUD Guidelines (HUD, 1990) standards. Since the HUD Demo and Denver 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 post-intervention declines 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 may be disappointing to some. The remaining lead in the blood (20-29% declines leave about 75% of the lead 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 sources besides the child's primary residence. Since bone-lead stores could not by themselves keep blood-lead levels elevated for 12 months post-abatement (Rust et al., 1999), the latter reasons seem plausible as contributors to elevated blood-lead concentrations.

There was evidence to suggest that lead-based paint abatement, by itself, may not completely eliminate lead exposure, because of the potential recontamination from unabated sources. In the Denver CAP Study (USEPA, 1996a, 1996b), geometric mean lead concentrations in unabated air ducts and soils were found to be significantly higher in abated houses as compared to control houses that contained little or no lead-based paint. Moreover, geometric mean dust-lead loadings in window wells were above HUD Guideline levels (800 µg/ft^2) for both abated and control houses.

Interim control methods were employed in two studies. 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 partial removal of 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; Aschengrau et al., 1994, Aschengrau et al., 1997) 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 EP 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).

The three educational intervention studies employed in-home educational visits by trained personnel. These 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 lead exposure. 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 (USEPA, 1996c; Schultz et al., 1999) and Milwaukee Prospective Educational Intervention Study (Schultz et al, 1998) reported 21% and 23% declines, respectively, 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 abatement and interim controls. The Boston 3-City Soil Abatement Study (Weitzman et al., 1993; Aschengrau et al., 1994, Aschengrau et al., 1997) 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 one year following the abatements in phase 1. 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 1, 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 2, 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 1, though seasonal variation of a comparable magnitude has been identified previously in children's blood-lead levels (USEPA, 1995c, 1996d). 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.

Summaries of each study described in this section are found in Appendix C.

3.2 RECENT LEAD HAZARD INTERVENTION STUDIES

A variety of approaches were employed in an attempt to identify new studies addressing the effectiveness of lead hazard intervention. These included the authors' knowledge of the available literature, focused literature searches, an examination of the referenced articles cited in identified studies, and additional material provided by EPA.

Nineteen new intervention studies are summarized in this section, including one previously reported study for which additional information was available. A time-line graph locating the period during which the interventions were conducted, for both the studies included in the original edition and the new studies, is presented in Figure 3-1. Six of the new studies focused on lead-based paint abatement, four studies assessed dust abatement, three studies considered the abatement of lead-contaminated soil, and three studies examined educational interventions. Finally, three studies examined extensive, community-wide soil and dust abatement measures implemented in Canadian cities following the reduction or elimination of point source industrial emissions. These three studies are summarized together, in order to emphasize the similarities in approach and also because the primary source of lead was industrial emissions. Although addressing industrial emissions is not the primary focus of this report, these studies are relevant, because the intervention methods employed were similar to those being used to address lead-based paint hazards.

A detailed discussion of each of the 19 studies follows in chronological order, with the exception that the three Canadian studies are summarized together at the end. 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.

3.2.1 New York Paint Abatement Study

This study (Markowitz et al., 1996) sought to determine the effectiveness of a combination of remediation of household lead hazards, educational intervention strategies, and iron therapy on reducing blood-lead levels (PbB) in moderately lead poisoned children (25-55 µg/dL) in the absence of chelation therapy. The study targeted children who were referred to the Montefiore Medical Center Lead Clinic and were identified as having elevated blood-lead concentrations (between 25-55 µg/dL) between 1986 and 1992. A total of 206 children received a lead mobilization test with negative results, indicating none were qualified to receive chelation therapy. Of the 206 children enrolled, 93 underwent chelation therapy at least once during this

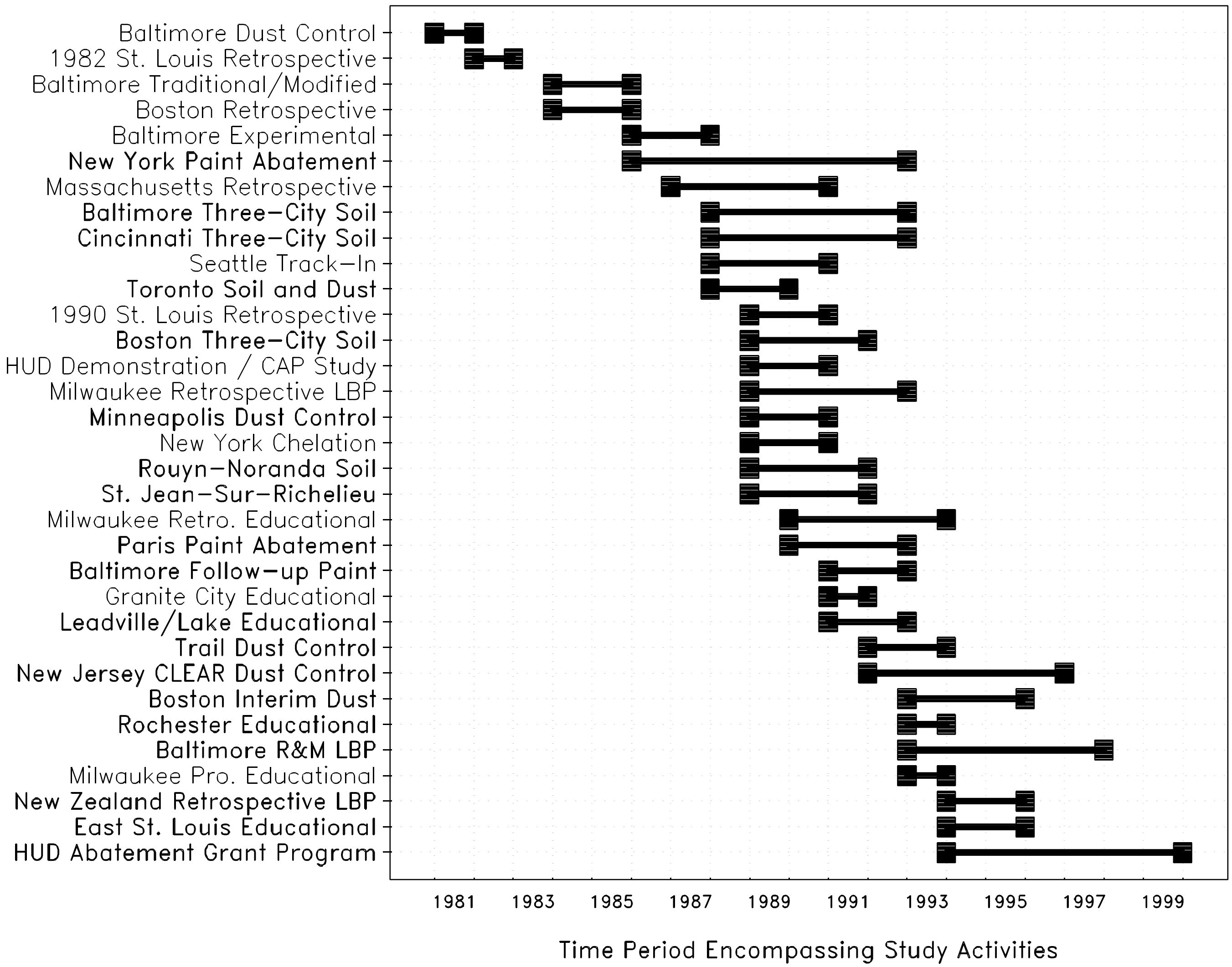


Figure 3-1. Time-Line for the Lead Hazard Intervention Studies, Combined Over Both Reports, with Studies Summarized in the Present Report Listed in Bold Face.

study, and only 79 of the remaining 113 children completed the study. The final study population consisted of 79 children ranging in age from 1 to 7 years (mean: 31.5 months at enrollment) who had not received chelation therapy prior to or during the study. Approximately two-thirds of the children were of Hispanic origin and one-third were African American.

Following inspection of the homes, the local Board of Health's Lead Bureau was notified to start the legal process needed to bring the home into compliance with existing health and housing codes. No specific abatement protocol was enforced. Education on sources of lead, its toxicity, and methods to reduce exposure to children was begun at the first clinic visit. Efforts were also made to reduce the child's exposure to lead hazards by placement in alternative lead-free housing during abatement of the child's residence. Nutritional counseling was begun at the first clinic visit and parents of children with ferritin levels less than 16 µg/L at enrollment were given supplies to provide their child with 5-6 mg/kg of elemental iron daily for 3 months for iron therapy. The intensive medical and environmental follow-up program consisted of 10 visits over a period of 6 months for each child and included three household visits by an XRF specialist and a nurse practitioner for environmental data collection. Blood-lead levels were obtained at each visit and ferritin levels were taken at 1, 7, and 24 weeks. The three home visits occurred at enrollment, 6 weeks, and at 24-25 weeks.

At each home visit, each residence was given a home environmental score (HES). This score consisted of a combination of the paint status and XRF readings in the home. Each painted surface was given a visual rating for its condition on a scale of 0 to 3. A score of 0 was given to an intact surface, 1 if the surface had bubbles, 2 to a surface with cracks, and 3 to a surface with peeling paint. The mean of triplicate XRF readings was calculated for each surface and then multiplied by the visual rating score. The HES given to each individual household is the sum of these products over all surfaces. Mean HES scores decreased throughout the study, as interventions took place. At enrollment, ten percent of households had a HES of 0, whereas 25 percent had a HES of 0 at 6 weeks, and 20 percent had a HES of 0 at 6 months.

The median HES score of 37 at the time of enrollment was used as a reference point to categorize the population into high- and low-level lead exposure. Mean blood-lead concentrations were greater for children with high HES scores (e.g., > 37) than for children with low HES scores. A significant correlation was found between PbB and HES at enrollment only

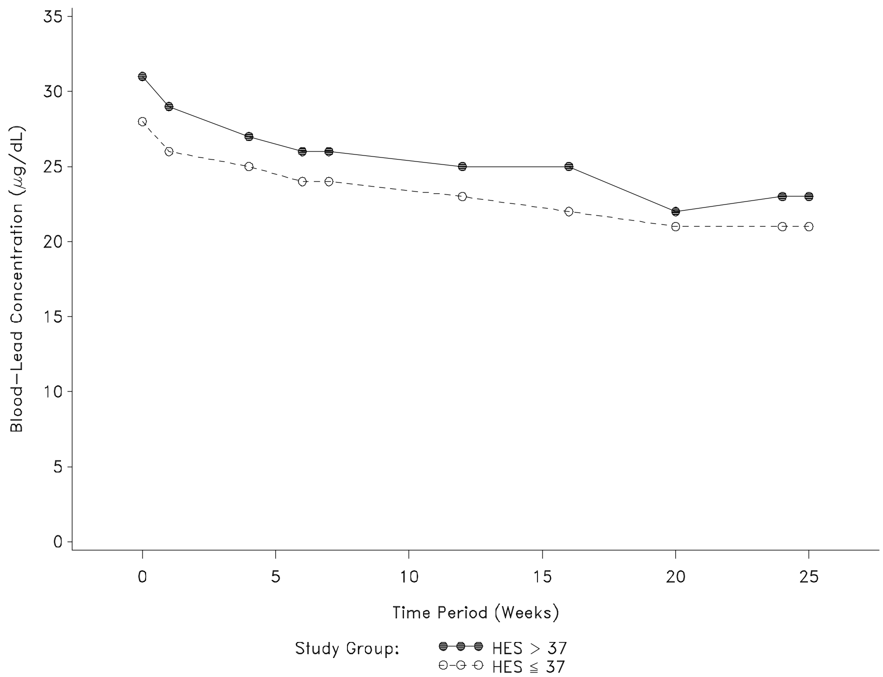


Figure 3-2. Average Blood-Lead Concentrations (µg/dL) by Initial Home Environmental Score (New York Paint Abatement Study).

(correlation=0.243, n=77, $p<0.05$). Average blood-lead levels declined for both HES groups throughout the course of the study (Figure 3-2). By 6 months post-intervention, blood-lead levels had declined to less than 25 µg/dL for two-thirds of the children, regardless of initial HES status. Only 7% of the children's blood-lead levels were less than 15 µg/dL at the end of the study, with the minimum blood-lead level at 9 µg/dL.

Two subgroups consisting of 10 children each whose HES scores were consistently above or consistently below the initial median HES score of 37 were chosen for further analysis. Children who were consistently above the median HES score had higher initial blood-lead levels than those who were consistently below the median HES score. However, mean blood-lead concentrations for both subgroups declined at a similar rate (Figure 3-3) over the 6 months of the study.

These results suggest that a combination of source abatement, educational intervention strategies, and iron therapy result in a 27 percent reduction in blood-lead for children with elevated blood-lead levels (between 22-55 µg/dL). Because comparable control population was

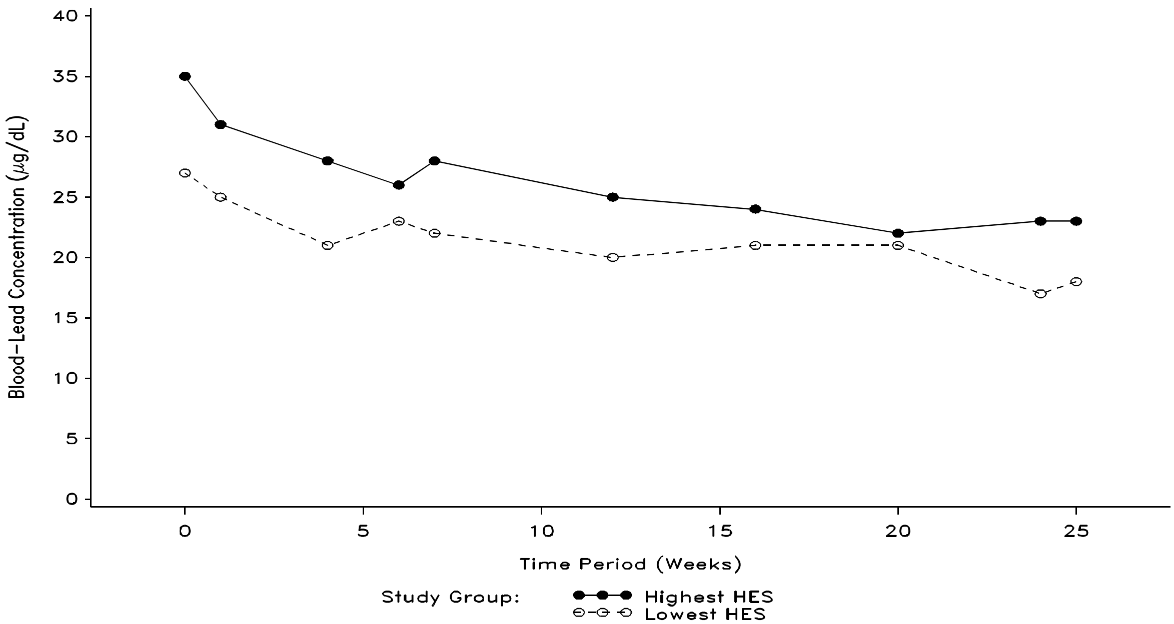


Figure 3-3. Average Blood-Lead Concentrations (µg/dL) by Child's HES Scores Consistently Above or Below the Initial HES Median of 37 at All Three Household Assessments (New York Paint Abatement Study).

evaluated, the magnitude of the reduction in children's blood-lead levels may be confounded with the effects of seasonal variation and the age of the child. Also, the authors note that no attempt was made to quantify the amount of time the child spent in the primary residence and other secondary residences. Although one measure of exposure was examined (HES), no measures were reported for the dust-lead content in the household and on the child's hands. It should be noted that the HES score does not take into account the varying amounts of deteriorated paint on the surfaces examined. A more reliable indicator would measure the area of deteriorated surfaces.

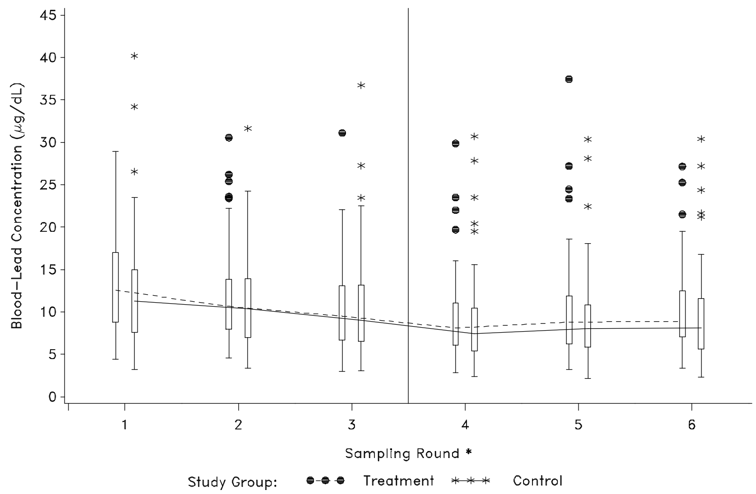
3.2.2 Baltimore Three-City Soil Abatement Study

This 1988-1991 study (USEPA, 1993b) was part of an EPA project examining whether a reduction in residential soil-lead concentration would result in a statistically significant decrease in blood-lead levels among children residing in the target homes. The cities of Baltimore, Cincinnati, and Boston were selected for this project. Each community also included specific objectives of its own in the project. For the Baltimore study, there was an additional interest in whether decreasing soil-lead levels would result in a corresponding decrease in household dust-lead levels.

The study took place over the course of three years, beginning in the Fall of 1988. Progress was measured through six rounds of blood sampling, with interventions conducted between rounds 3 and 4. The population studied consisted of Baltimore children aged 6 to 72 months residing in otherwise comparable communities designated the control or study areas. The designated areas were chosen for comparable demographic, soil lead and housing characteristics. An initial sample size of 408 children was chosen, with a total attrition of 294 children and total gain of 71 children through the six rounds of blood sampling. Sample sizes immediately prior to and after the interventions were 270 children (round 3) and 197 children (round 4). For the study group, intervention consisted of removing the top six inches of soil in areas with lead concentration greater than 550 ppm and replacing it with clean soil (i.e., less than 50 ppm). For both groups, exterior paint stabilization and repainting were conducted to prevent recontamination of the cleaned soil. The actual interventions occurred between rounds 3 and 4, beginning in the Summer and Fall of 1990 for paint stabilization and soil abatement, respectively. Data gathered were of three types: environmental (soil-, dust-, paint- and water-lead levels), biological (blood- and hand-lead levels) and questionnaire data. Biological and questionnaire data were collected every round while environmental data were obtained only before and after the abatements.

There was a statistically significant difference in study area soil-lead concentrations before and after abatement (decrease of 470.1 ppm). However, the decrease in dust-lead levels was not statistically significant for the study area, but was statistically significant for the control area. Decreases in blood-lead concentration for the study and control areas were observed at round 4, January through March of 1991, three months following intervention. In round 5, May through July, blood-lead levels increased slightly for both groups, remaining somewhat stable through round 6 (Figure 3-4).

Six linear regression models, with the log of blood-lead level or the log of hand-lead level as the response variable, were constructed. The independent variables included treatment group, socio-economic status, gender, age, season, dust-lead level, and soil-lead level. For each model,



* Vertical line between rounds 3 and 4 indicates interventions were conducted at that time.

Figure 3-4. Distribution of Blood-Lead Concentration by Sampling Round and Study Group (Baltimore Three-City Soil Abatement Study).

regression coefficients were calculated for all six rounds, separately for children who did and did not participate in all six rounds. The geometric mean of the blood-lead levels, for children participating in all six rounds, decreased from 9.44 µg/dL in round 3 to 8.36 µg/dL in round 4 for the treatment group and, 9.28 µg/dL in round 3 to 7.59 µg/dL in round 4 for the control group.

Thus, on average, a child assigned to the treatment group had a decrease (from round 3 to 4) in blood-lead level of 14% compared to a decrease of 22% for a child assigned to the control group. For the remaining two rounds, the geometric mean blood-lead levels for the control group remained lower than for the study group, although the differences were not statistically significant.

The results indicate soil abatement did not produce significant declines in the mean blood-lead concentrations of children benefitting from the abatements. The authors hypothesize that perhaps this was due in part to the low levels of soil lead in the study area. Nevertheless, soil abatement may not be an effective method for lowering the blood-lead levels of urban children. However, in some cases, soil abatement may serve as a helpful adjunct.

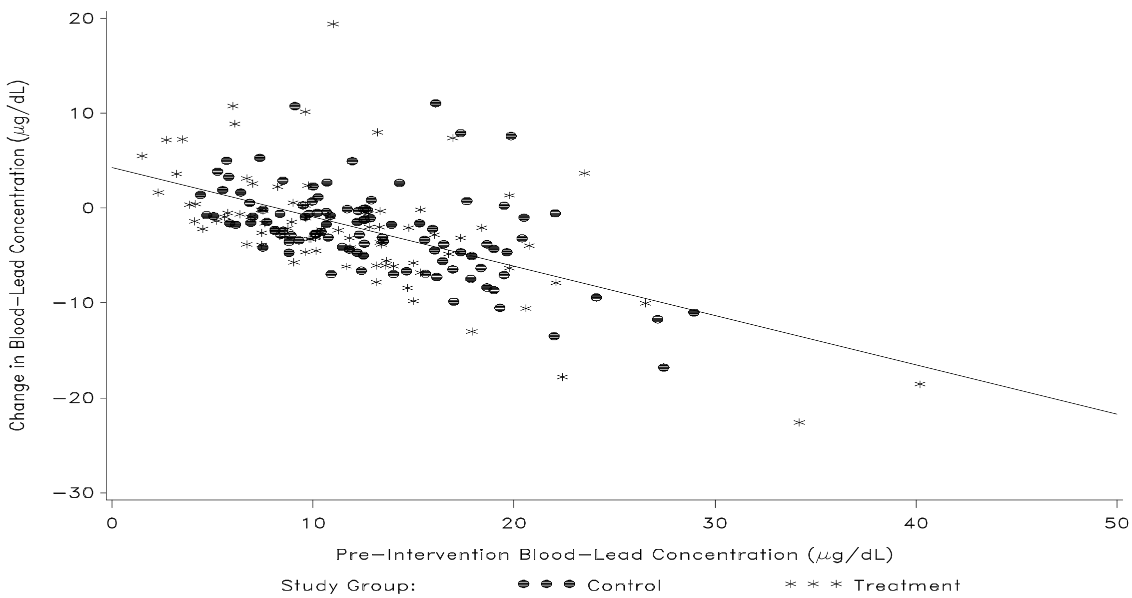


Figure 3-5. Change in Blood-Lead Concentration Between Rounds 1 and 6 Plotted Against Pre-Intervention Blood-Lead Concentration (Baltimore Three-City Soil Abatement Study).

Blood-lead concentration change from round 1 to round 6 appears to be negatively associated with round 1 blood-lead concentration in an approximately linear fashion (Figure 3-5). In other words, children with low initial blood-lead concentration had an increase by round 6,

while children with high initial blood-lead concentration had a decrease by round 6. This may be due in part to "regression to the mean."

3.2.3. Cincinnati Three-City Soil Abatement Study

This 1989-1991 study (USEPA, 1993c) was part of an EPA project examining whether reduction of soil and dust-lead levels would result in a statistically significant decrease in blood-lead levels of children. Three cities, Baltimore, Boston, and Cincinnati were selected for this project, with each community setting additional study objectives. The Cincinnati study was also interested in whether interim interior dust abatement, in conjunction with exterior dust and soil abatement, would result in a greater reduction in blood lead than dust and soil abatement alone.

Families with children under five years of age were recruited from three study areas (A, B, and C) selected for similar demographic and housing characteristics. Also, areas chosen primarily consisted of rehabilitated housing in which lead-based paint had been abated as a result of HUD-supported programs in the early 1970s. Rehabilitation involved the "gutting" of buildings and the complete replacement of plumbing, wiring, and heating systems, and installation of new walls, flooring, windows, and doors. Lead levels in rehabilitated housing are probably quite low, however, lead-based paint could be present due to maintenance/repainting prior to the 1978 ban of lead in residential paint. For intervention, area A received soil lead, exterior dust, and interior dust abatement treatments in 1989. Soil-lead abatement consisted of the removal of the top 6 inches of soil if the 15 cm core average or top 2 cm lead concentration was greater than or equal to 500 ppm. Interior dust abatement consisted of vacuuming and/or wet cleaning surfaces including ledges, window wells and window sills and non-carpeted floors. Contaminated carpets and selected furniture were replaced since vacuuming was determined ineffective for abatement. Exterior dust abatement consisted of vacuuming paved areas.

The study took place through nine phases of environmental and biological monitoring. An earlier "phase", phase 0, involved the project design and initial measurements. Two hundred and twenty-five children were enrolled in phase 1 (June and July of 1989), of which 173 resided in rehabilitated housing. One hundred of the initial 225 remained at the completion of the study in October 1991. Also, 66 phase 5 recruits (January of 1990), of which 37 remained, and 16 new births contributed to a final tally of 153 participants at the end of the study. Interior and exterior dust and soil abatement for Area A and interior dust abatement for Area B took place between phases 1 and 2. Exterior dust and soil abatement for Area B took place between phases 5 and 6. Area C served as a control, although all three forms of abatement were provided after phase 9.

For Area A, the geometric mean soil-lead concentration decreased from 200 ppm to 54 ppm between phases 0 and 5 for the top 2 cm core composite samples. This decrease was statistically significant ($p < 0.05$). For Area B, the geometric mean soil-lead concentration for the top 2 cm core composite samples decreased from 161 ppm in phase 5 to 59.5 ppm in phase 9. The overall log of interior floor dust-lead loading decreased in Area A between phases 1 and 3 (Figure 3-6), remaining essentially constant in Area C, with the lowest original lead loading.

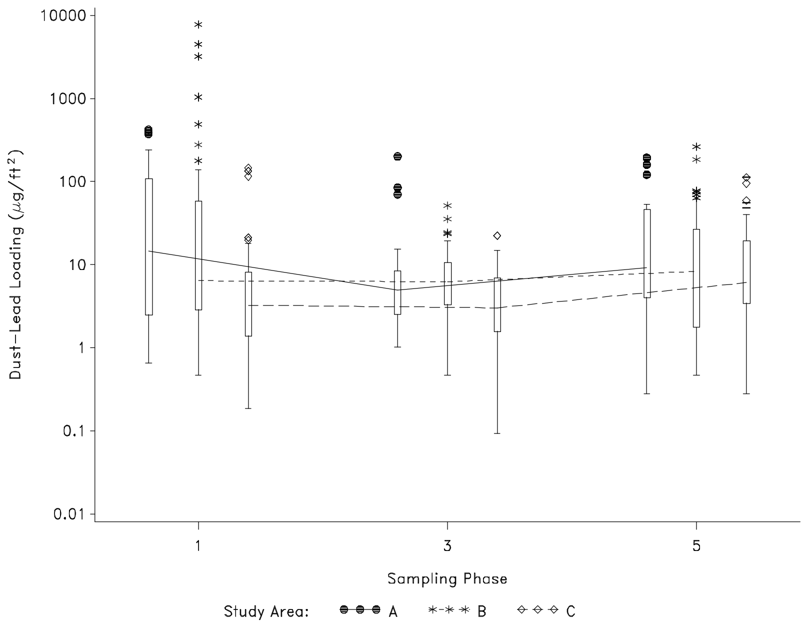


Figure 3-6. Distribution of Interior Floor Dust-Lead Loading by Sampling Phase and Study Area (Cincinnati Three-City Soil Abatement Study).

For initial recruits living in rehabilitated housing and participating in phases 1 and 9, mean differences in blood-lead concentrations, measured between both phases, were 0.64, -2.04, and -1.72 (µg Pb /dL) for Areas A, B, and C, respectively. From baseline, these changes represent an increase of 7% and decreases of 16.4% and 17.3% for Areas A, B, and C, respectively. The difference between the changes in Areas A and B was statistically significant. However, in comparing blood-lead concentrations for all children in the study, the median blood-lead concentration was lower at phase 9 than at phase 1, for all study areas (Figure 3-7). The increase in mean differences of blood-lead concentration for Area A children could be due to the fact that mean blood-lead concentration was lower at baseline (9.44 µg/dL) for Area A children than for Area B and C children (12.38 µg/dL and 9.96 µg/dL), respectively.

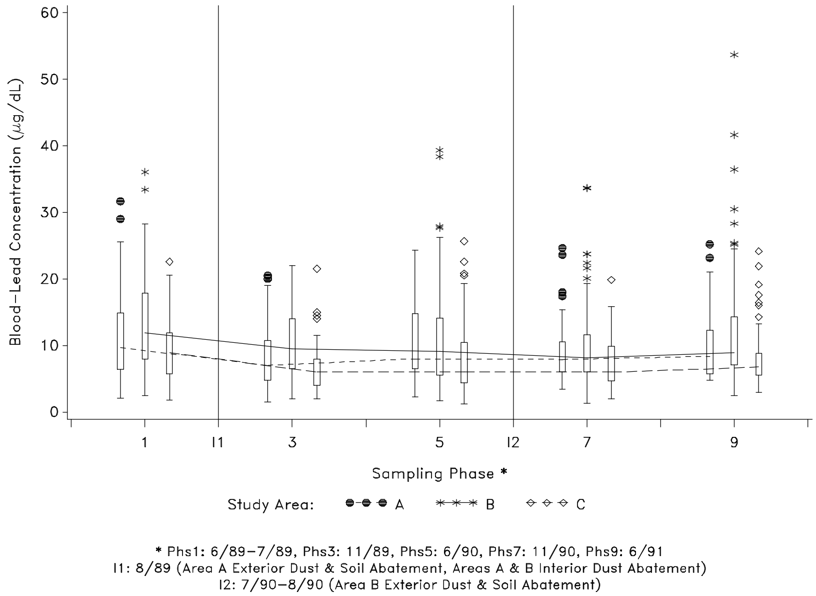


Figure 3-7. Distribution of Blood-Lead Concentration by Sampling Phase and Study Area (Cincinnati Three-City Soil Abatement Study).

Results indicate soil abatement can be effective in the long term for reducing lead levels in soil. However, there is no conclusive evidence that the abatement methods chosen were effective in long-term reduction of interior and exterior dust lead. More importantly, there is no evidence that the three forms of abatement together reduce blood-lead levels in the long term nor is there evidence that such a combined abatement is more effective than interior dust abatement alone. Two possible contributing factors in the blood-lead concentration change are baseline blood-lead concentration and season. First, the blood-lead concentration change from baseline to phase 9 appears to be negatively associated with baseline blood-lead concentration in a fairly linear fashion. Children with low initial blood-lead concentration had an increase by phase 9, while children with high initial blood-lead concentration had a decrease by phase 9 (Figure 3-8). Again, the trend intercepts above zero. Second, the mean change in blood-lead concentration from phase 1 to phase 3 was -1.86, -l.86, and -2.55 for Areas A, B, and C, respectively (among initial recruits living in rehabilitated housing and participating in both phases). However,

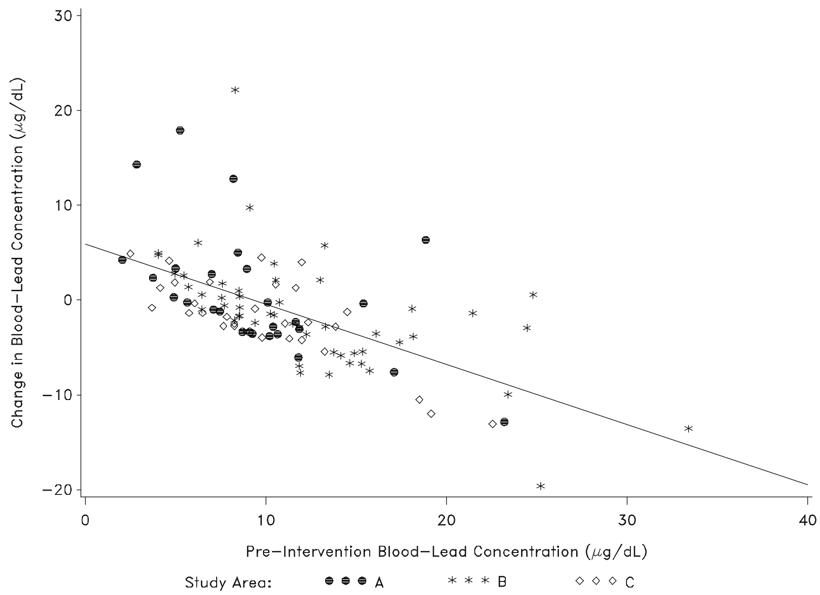


Figure 3-8. Change in Blood-Lead Concentration Plotted Against Pre-Intervention Blood-Lead Concentration (Cincinnati Three-City Soil Abatement Study).

phase 1 was conducted in June of 1989 while phase 3 was conducted in November of 1989. Thus, decreases in blood-lead level could have been in part due to seasonal variation.

3.2.4 Boston Three-City Soil Abatement Study (Updated)

This 1989-1991 project (Weitzman et al., 1993; Aschengrau et al., 1994; Aschengrau et al., 1997) 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, and also assessed the impact of residential lead-based paint hazard remediation alone and in combination with soil abatement on children with mildly elevated blood-lead levels. 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, including 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. Occupants and their belongings were relocated off site during the interior remediations.

During Phase I, the average blood-lead concentrations in all three experimental groups decreased at the first (6 months) post-abatement measurement (Figure 3-9). 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.

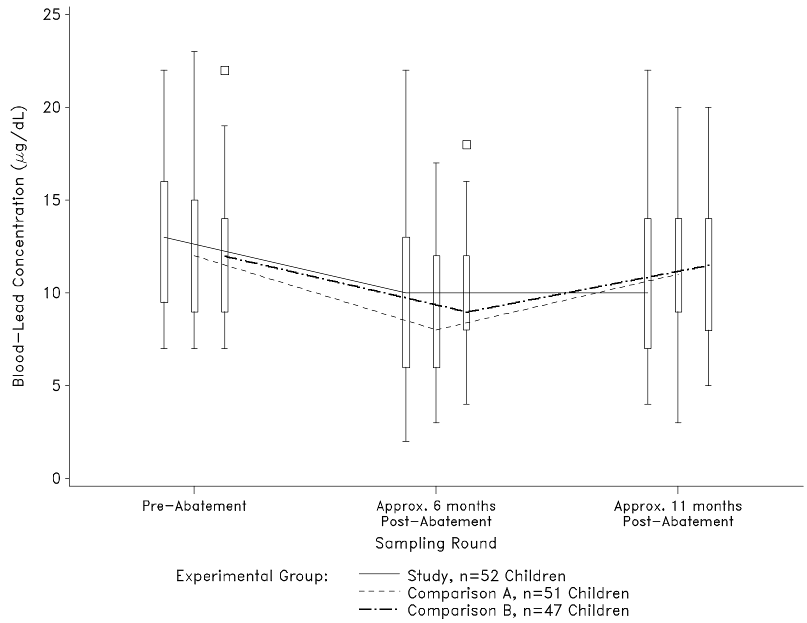


Figure 3-9. Arithmetic Mean Blood-Lead Concentration Across Sampling Rounds and Experimental Groups, Phase 1 (Boston Three-City Soil Abatement Study (Updated)).

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. 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 3-10). 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).

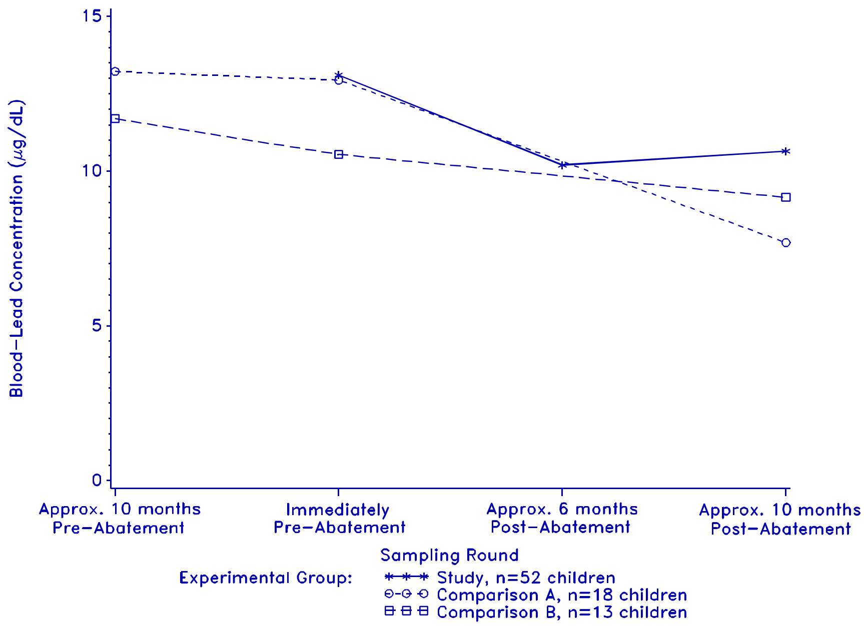


Figure 3-10. Arithmetic Mean Blood-Lead Concentration Across Sampling Rounds and Experimental Groups, Phase I and II (Boston Three-City Soil Abatement Study (Updated)).

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.

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 3-11). The authors hypothesize that this increase was due to recontamination by lead contaminated soil still present in surrounding yards. 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.

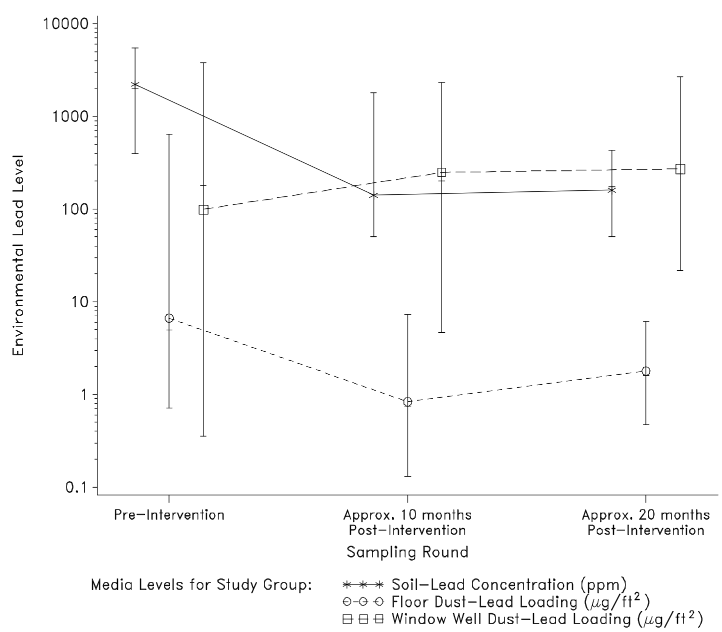


Figure 3-11. Arithmetic Mean Environmental Lead Level (For Study Group) Across Sampling Rounds (Boston Three-City Soil Abatement Study (Updated)).

Mean blood-lead concentrations of Study Group children whose homes received paint hazard remediation during Phase II were an average of 2.6 µg/dL higher than those of children who received no Phase II interventions. Mean blood-lead concentrations for children whose homes received both paint hazard remediation and soil abatement during Phase II were an average of 1.4 µg/dL higher than that of children whose homes received soil abatement only (Comparison Groups A and B combined).

To evaluate the effectiveness of lead-based paint abatement, a multivariate model analysis was conducted for comparison of Phase II post-intervention blood-lead concentrations to Phase II pre-intervention blood-lead concentrations. After controlling for confounding factors in the model (e.g., age, sex, race, socioeconomic status, mouthing, hand-washing, housing characteristics, and environmental sources of lead), paint hazard remediation was associated with a statistically significant ($p=0.05$) increase of 6.5 µg/dL in blood-lead levels in the Study Group. Paint hazard remediation was associated with an increase of 0.9 µg/dL in blood-lead levels ($p=0.36$) in Comparison Group A and B homes that received paint and soil abatement, compared to those that received only soil abatement.

Although mean floor dust-lead loading levels showed an increase in all households following the Phase II interventions, the increase was greater for homes that received paint hazard remediation. Mean floor dust levels increased by 142% for Study Group households that received paint interventions and by 75% for those not receiving paint interventions. Comparison Groups A and B combined showed an increase of 42% for homes receiving paint and soil abatement and by 33% for homes receiving only soil abatement. Mean post-intervention window sill dust-lead loading levels increased by 105% for the Study Group and remained unchanged (+2%) for Comparison Groups A and B combined for those homes receiving paint hazard remediation, but decreased in homes that did not (-42% for the Study Group and -41% for Comparison Groups A and B combined). These increases in dust-lead leadings may be due to dust-generating abatement practices, along with inadequate cleanup and clearance testing.

These results suggested that abatement of lead-based paint around homes may result in a significant increase in blood-lead levels. However, the removal of lead-contaminated soil may offset this increase. For Phase I, results indicate that abatement of lead-contaminated soil by itself may result in a moderate 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 (USEPA, 1995c, 1996d). 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 variations.

3.2.5 Minneapolis Dust Intervention Study

This study (Mielke et al., 1994) sought to reduce children's blood-lead concentrations by reducing exterior soil and dust lead and interior dust lead at targeted residences in the Minneapolis and St. Paul, Minnesota, inner-city areas. The study population consisted of 40 primarily minority children identified by the Twin Cities Mapping Project as living in high soil-lead concentration communities. Twenty-three children from Minneapolis were targeted for treatment by the dust control intervention, whereas 17 children from St. Paul received no dust control treatment.

For the 23 treatment group children, interior dust control consisted of wet wiping walls to remove loose paint chips, followed by a thorough vacuuming using a high efficiency particle accumulator (HEPA) vacuum. Floors were mopped with a high phosphate detergent and some carpets were removed from the household. Households with children exhibiting the highest blood-lead concentrations were provided more intensive dust control treatment than those with children exhibiting lower concentrations. Exterior interventions included covering bare soil with sod or wood chips, the addition of a sandbox, and provisions to prevent soil from washing onto sidewalks (thereby limiting the opportunity for dust track-in). Parents of children in the treatment group were supplied with dust control information and cleaning supplies. Only prevention information was provided to the parents of the control group children. Venous blood samples were collected and analyzed by the Minneapolis Children's Medical Center. Soil-lead loadings were collected by a 2.5 cm deep soil scrape sample at foundation, mid-yard and street-side locations. Interior dust lead samples were collected, however, those results were not reported.

Pre- and post-intervention blood-lead levels were taken during May-June and September-November 1990, respectively. The distributions of pre- and post-intervention blood-lead levels are displayed in Figure 3-12. Among treatment group children, 52% of the children's blood-lead concentrations decreased, 4% increased, and 44% remained the same (follow-up measurement within ±1µg/dL of initial blood-lead concentration). In the control group, 29% of the children had a reduction in blood-lead concentration, while 53% exhibited an increase, and 18% remained the same. Blood-lead concentrations were said to decrease/increase if the post- versus pre-intervention concentration difference exceeded the quality control limit of 1 µg/dL. By the end of the study, all children in the treatment group had blood-lead concentrations less than 25 µg/dL and the percentage of children above 14 µg/dL was reduced from 39% to 30%. In the control group, the percentage of children above 14 µg/dL increased from 41% to 53% by the end of the study. Three of these children had follow-up blood-lead levels of 40, 41, and 61 µg/dL, prompting medical intervention. Average differences between initial and follow-up blood-lead concentrations in the treatment and control groups were statistically significant ($p=0.006$) by the Fisher-Pitman test, suggesting that dust control procedures were effective.

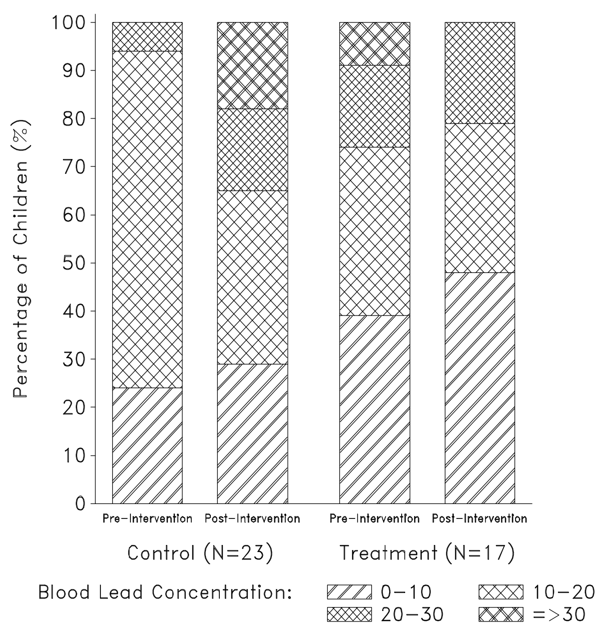


Figure 3-12.   Distribution of Blood-Lead Concentration (µg/dL) for Pre- and Post-Intervention Measures, by Study Group (Minneapolis Dust Intervention Study).

Post-intervention soil-lead concentrations for the treatment group were significantly ($p<0.001$) lower than initial concentrations. Foundation and mid-yard soil-lead concentrations were reduced by a factor of three to four. Soil-lead loadings were also reduced. Post-intervention soil lead samples were not collected for the control group, but were assumed to have remained unchanged. Interior dust-lead levels were not reported.

The dust control treatment program appears to have resulted in reductions in children's blood-lead concentrations for the treatment group as compared to the control group. By the end of the study, all of the children in the treatment group had blood-lead levels less than 25 µg/dL, while 24% of control group children had blood-lead levels greater than 25 µg/dL. Interpretation of the study results is difficult, because interior dust-lead levels were not reported. Both interior paint stabilization and the exterior intervention may have had an impact on children's blood-lead concentrations in the treatment group. While the reductions in the blood-lead concentrations observed in some of the control group children may have been due to random variation, the authors suggest that some of the reductions may be accounted for by information given to parents on dust control. Also, some of the observed increases in blood-lead levels may be explained by seasonal variation, since blood-lead levels tend to increase during Summer months. Although the study had a control population, children were not randomly assigned to the treatment and control groups. Thus, changes in blood lead due to treatment are confounded with any differences between the two populations. There was no discussion on how comparable the two populations were (i.e., age differences, gender, etc.). However, a Chi-square test of homogeneity did not detect significant differences in the initial distribution of blood-lead levels between the treatment and control groups. Although the sample sizes in this study were small, gross differences in the initial distribution would be detectable using this test.

3.2.6 Paris Paint Abatement Study

This study (Nedellec et al., 1995) sought to determine the effectiveness that lead-based paint abatement would have in reducing severely elevated blood-lead concentrations (PbB) in children. The study targeted children less than 6 years of age who were identified as severely lead-poisoned by the Maternal and Child Care Centers (PHI) of Paris between January 1990 and February 1992. A total of 190 households were visited, from which, a subset of 59 homes containing 205 children were considered priorities for intervention activities.

For the 190 households visited, a score (0 to 5) was given to each household to assess the state of deterioration of the building and apartment. The score was determined as a function of the general condition of the building, its maintenance, the cleaning of the floor, and the condition of the paint on the walls and woodwork. Paint samples were collected in 147 of the 190 homes visited, and the maximum lead content of paint was found to be greater than 1.5 mg/g in 93% of the homes and greater than 10 mg/g in 77% of homes. The characteristics of the 59 homes selected for abatement did not differ significantly from the total number evaluated in that the maximum lead content in paint for the 59 homes exceeded 1.5 mg/g in 58 (98%) homes and exceeded 10 mg/g in 52 (88%) of them.

The one-time intervention consisted of chemical stripping with caustic products, encapsulation, replacement of antiquated elements and coatings of lead-based paints, and a final dust cleaning. Stripping was used on 52% of the items abated, a combination of stripping and encapsulation was used on 36% of the items abated, and a combination of encapsulation and replacement on 12% of the abated items. Families were relocated during the performance of the abatements. Dust samples were collected in 29 homes at baseline, during the intervention, 1 to 2 months, 3 to 6 months, and 7 to 12 months post-intervention. Venous blood samples were taken at baseline and at least 2 times post-intervention.

Dust sample data were available for 24 of the 29 households in which samples were collected. Characteristics of these 24 homes were compared to the other 35 homes for which dust sample data were unavailable. Initial conditions appeared to be slightly less severe in homes where dust samples were collected. Median dust-lead loadings measured 83.6 µg/ft^2 at pre-intervention and showed an increase of 697 µg/ft^2 during the intervention activities. Post-intervention dust-lead loadings showed a median decrease of 33.9 µg/ft^2 at 1 to 2 months and 45.4 µg/ft^2 at 3 to 6 months follow-up. For 11 homes that had an initial dust-lead loading greater than 92.9 µg/ft^2, median decreases were 144 µg/ft^2 one to two months and 157 µg/ft^2 3 to 6 months following intervention. By 6 to 28 months post-abatement the maximum dust-lead loadings were less than 92.9 µg/ft^2 for 40 out of 45 households sampled.

Pre- and post-intervention blood-lead levels were available for 78 of the 205 children residing in 41 of the 59 homes. Compared to the other 18 households for which no post-intervention blood data were available, households where blood-lead concentrations were available for both pre- and post-intervention were significantly more deteriorated than for the other families. In addition, the maximum pre-intervention blood-lead level was significantly higher in these homes. The maximum paint lead content was lower; however, the paint lead concentration was already very high for both groups. All of the children's blood-lead concentrations decreased significantly post-intervention, with the exception of 4 children (living in 2 of the 41 homes) whose blood-lead level increased.

A multiple linear regression model was conducted on the data from the 74 children whose blood-lead levels decreased post-intervention. The model regressed the natural logarithm of blood-lead levels on the following dependent variables: Time (weeks) after screening, Time (weeks) after intervention, Age (0 for < 3 years, 1 for ≥ 3 years), After Chelation Therapy (0 for no chelation performed, 1 for chelation performed), $15 < PbB < 45$ (1 if $15 < PbB$ 45, 0 otherwise), $PbB \geq 45$ (1 if $PbB \geq 45$, 0 otherwise), and After Intervention (0 if pre-intervention, 1 if post-intervention). The 4 children whose blood-lead concentrations increased post-intervention were excluded from the regression analysis, presumably because the children were exposed to high levels of lead-contaminated dust during the intervention since their families may not have been relocated.

The results suggest that the intervention was beneficial to severely lead poisoned children exposed to severe pre-intervention conditions. The one time intervention seemed to have had a lasting effect in reducing interior dust-lead levels. As noted by the substantial increase in dust-lead loadings during the abatements, families should be relocated during the rehabilitation process. Since specific guidelines were not set for the abatement process itself, comparisons on a house-to-house basis may not be feasible. The magnitude of the reduction in blood-lead levels may also be confounded with seasonal variation, as sampling occurred at various time intervals. Furthermore, the decline is confounded with chelation therapy, which was provided to some of the more severe lead poisoned children.

3.2.7 Baltimore Follow-up Paint Abatement Study

This study (MDE, 1995) sought to evaluate the effectiveness of alternative lead-based paint abatement procedures on long-term reduction in household dust-lead levels in homes in Baltimore, Maryland. A total of 72 homes were included in the study. These homes were abated between January 1, 1991, and June 30, 1992, using alternative methods. All households had at least one clearance dust-lead measurement taken. The alternative intervention methods consisted of 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. Wipe dust-lead loading samples were taken from floors, window sills, and window wells in rooms where the child spent time. The study was limited to homes where at least one clearance sample was available. Additional samples were collected in 75 homes where follow-up sampling had not been conducted.

Sixty-nine of the 72 homes had at least one floor clearance sample, 67 had at least one window sill clearance sample, and 57 had at least one window well clearance sample. Three time intervals (approximately 6, 12, and 19 months post-intervention) were used to group the follow-up dust measurements. Figure 3-13 displays the changes in geometric mean floor, window sill, and window well dust-lead loadings at each follow-up interval. Geometric mean floor dust-lead loadings seemed to remain fairly constant over the course of this study at levels below 26 µg/ft^2, whereas window well dust-lead loadings showed recontamination fairly quickly. Clearance levels for floors, window sills, and window wells were set at 200 µg/ft^2, 500 µg/ft^2, and 800 µg/ft^2, respectively. By 19 months post-intervention, only 5% of the homes were above clearance for floors, while 42% and 47% of the homes were above clearance levels for window sills and window wells, respectively.

These results seem to indicate that for alternative abatement methods, dust-lead loadings on floors can be kept fairly low over long-term time periods. Floor surfaces showed little evidence of recontamination. However, reaccumulation of lead-containing dust occurred in

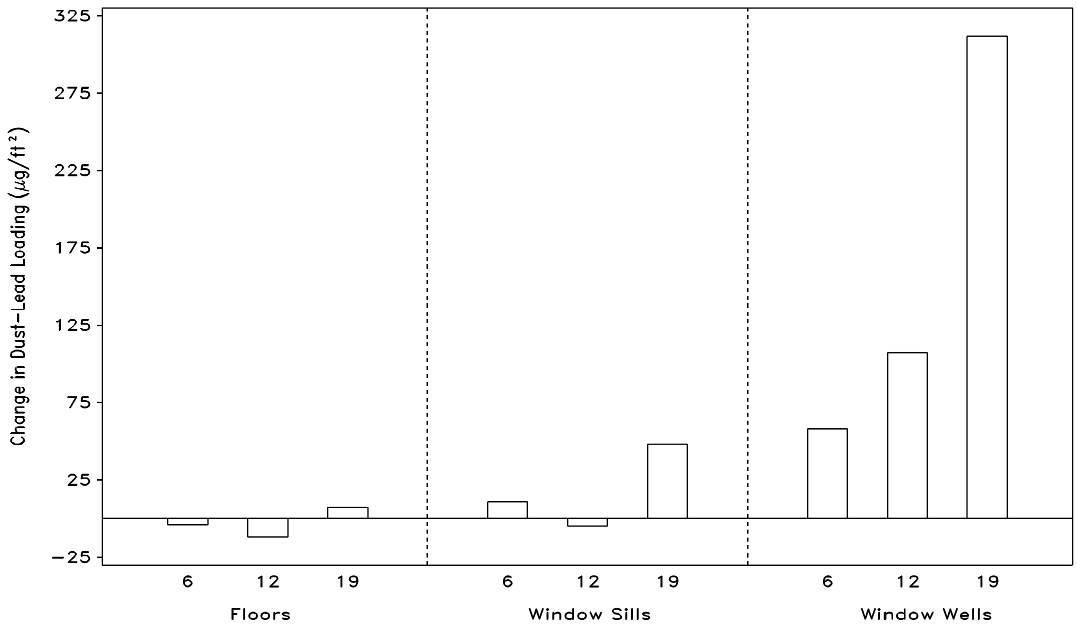


Figure 3-13. Changes in Geometric Mean Floor Dust-Lead Loading (µg/ft²) by Time Interval and Surface Type (Baltimore Follow-up Paint Abatement Study).

window sills and window wells at each time interval examined. Reaccumulation was greatest for window wells with 17%, 43%, and 47% of homes at or above clearance standards by the 6, 12, and 19 month time intervals, respectively.

3.2.8 Leadville/Lake County Educational Intervention Study

This screening study (LCDH and UC, 1993) compared community blood-lead concentrations in 1992 with those determined in 1991, and evaluated the effect of educational intervention on blood-lead levels of children whose pre-intervention level was elevated, or who lived in residences with unusually high concentrations of lead or arsenic in the surrounding soil. The sampled population consisted of 160 individuals, including 127 children. One hundred thirteen of the 127 children were less than 72 months of age. If a child's blood-lead concentration was 10 µg/dL or higher, parents received instruction on methods to reduce their child's lead intake. Venous blood samples were taken during the two Fall screening clinics conducted one year apart. A 20% random sample of families who had blood lead measurements during the 1991 Fall screening clinic were targeted for the 1992 screening.

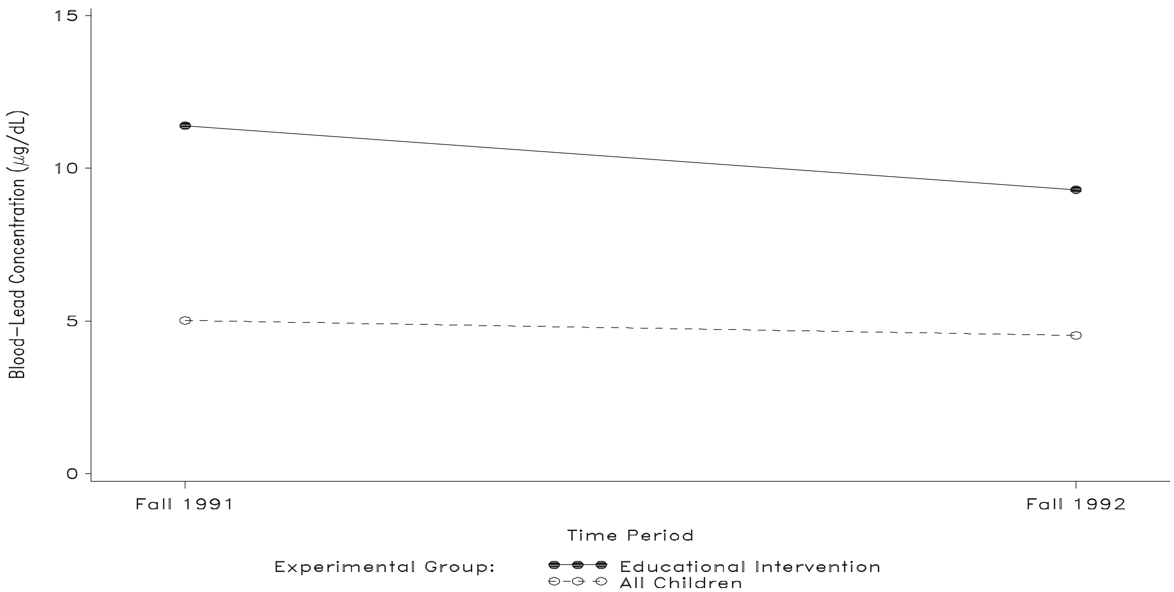


Figure 3-14. Geometric Mean Blood-Lead Concentration for All Children (n = 66) and for Children Who Received Educational Intervention (N = 8) (Leadville/Lake County Educational Intervention Study).

A total of 66 children were tested in both 1991 and 1992. Blood-lead concentrations for these children declined 9.8%, from a geometric mean of 5.02 µg/dL to 4.53 µg/dL, during the year (Figure 3-14). Twenty-six of these children had not moved during the year. Their geometric mean blood-lead level declined 25%, from 5.83 µg/dL to 4.38 µg/dL. Eight children were identified as having elevated (>10 µg/dL) blood-lead levels in 1991. These children showed an average decline in blood-lead concentrations of 19%, from a geometric mean of 11.4 µg/dL to 9.3 µg/dL. Two of these children had reductions in blood-lead concentrations of 49% and 57%.

For children in the Leadville/Lake county areas, blood-lead concentrations declined on average by approximately 10% during the one-year period. In comparison, 8 children benefitting from educational intervention showed a 19% decline on average. These 8 children were targeted because they exhibited elevated blood-lead concentrations at the initial survey, so the observed decline may be due in part to non-interventional factors such as regression to the mean, or merely age-related variation. The absence of a comparable control population makes assessment of these issues difficult.

3.2.9 Trail Dust Intervention Study

A variety of intervention strategies (Hilts et al., 1995; 1998; Hilts, 1996) have been implemented in Trail, British Columbia, with the goal of reducing children's blood-lead levels in the presence of ongoing emissions from a lead and zinc smelting facility. Intervention strategies have targeted lead-containing house dust. Of particular interest is a study that sought to determine the effectiveness of repeated vacuuming using high efficiency particle accumulator (HEPA) vacuums in reducing both household dust-lead loading (PbD) and children's blood-lead concentrations (PbB) (Hilts et al., 1995). In addition, community education, greening, and dust control programs have been implemented along with residential bare soil reduction and individual case management programs (Hilts, 1996). Soil abatement was not performed, because of ongoing smelter stack emissions.

HEPA Vacuum Study

The sample population for this study consisted of 207 households in higher risk areas of Trail, British Columbia, with children under six years of age who had participated in a 1992 blood lead screening. Of the 207 families, 122 agreed to participate in the study. The children were randomly assigned to treatment and control groups (61 children in each group). Fifty-five treatment group children and 56 control group children completed the study. Families in both groups, however, received educational materials and recommendations to reduce childhood lead body burden, and were advised to continue their normal cleaning habits throughout the course of the study. In addition, the treatment group received a dust intervention consisting of HEPA vacuuming of accessible finished floors once every six weeks over a period of ten months, from November 1992 through August 1993. The control group did not receive these vacuumings. Hand wipe and floor dust-lead samples were collected three times during the study for both treatment and control homes. Baseline and post-intervention venous blood samples were collected at Fall screening clinics approximately one year apart. Additionally, a 19-part self report survey was administered at the time of the post-intervention blood lead screening.

Small decreases in blood-lead concentrations were observed during the study in both study groups (Figure 3-15), however, the difference in pre- and post-intervention changes in blood-lead concentrations between the treatment and control group was not significant (p=0.85). During the first vacuuming cycle carpet dust loading, carpet dust-lead loading, and carpet dust-lead concentration were reduced by 34, 39, and 8 percent, respectively, as compared to their measures prior to vacuuming. Similarly, carpet dust loading, carpet dust-lead loading, and carpet dust-lead concentration were reduced by 34, 35, and 3 percent during the fourth vacuuming cycle, and by 46, 47, and 0 percent, respectively, during the seventh cycle. During the study, geometric mean hand-wipe lead loading decreased significantly for the control group, while a marginally significant increase was observed in the treatment group during the study. The authors hypothesized that this may stem from families relaxing their hygiene efforts because of a perceived reduction in exposure risk due to the intervention. Carpet dust loading increased for the control group and decreased significantly for the treatment group ($p<0.01$). Carpet dust-lead loading also decreased significantly for the treatment group ($p<0.01$).

Eighteen households were sampled weekly for evidence of recontamination for a period of six weeks after the final vacuuming cycle in August 1993. In these 18 homes, carpet surface dust-lead loadings had declined by approximately 50 percent immediately following the final vacuuming. However, recontamination occurred within 2-½ to 3 weeks, on average. In addition to the dust recontamination sampling, a self-report survey questionnaire was completed by 103 of the study participants at the post-intervention blood lead screening. Children living in homes where people removed their shoes at the door tended to have lower blood-lead levels and floor dust-lead loading tended to be lower also. Children who had pets tended to have higher blood-lead levels and higher floor dust-lead loadings.

Although HEPA vacuuming every 6 weeks did not have a significant impact on blood-lead levels, there was some evidence to suggest that more frequent vacuuming might be beneficial. A follow-up study was conducted in 17 homes located in high risk neighborhoods (Hilts, 1996). Families in the follow-up study received HEPA vacuuming, wet-mopping, and wet-wiping biweekly during the summer months. The intervention strategy tested in the follow-up study was effective in preventing a seasonal rise in dust-lead loadings on carpets, but less effective in preventing a rise in blood-lead concentrations. The average carpet dust-lead loading stayed the same in treated homes, but nearly doubled in 14 comparison homes during the study period. The average blood-lead concentration rose by 2.9 μg/dL in the treatment group and

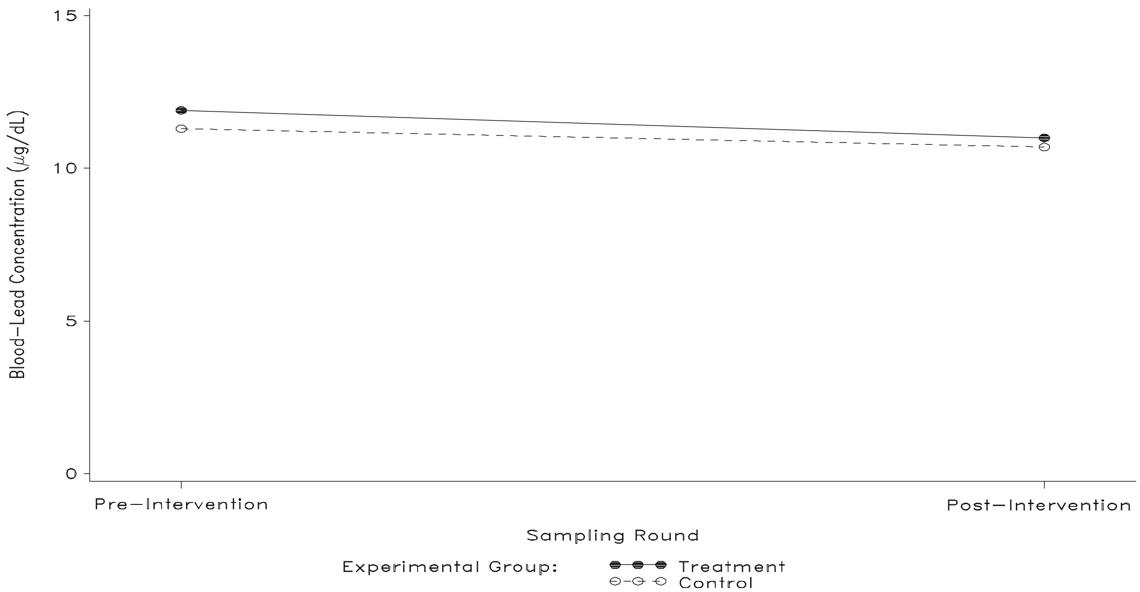


Figure 3-15. Geometric Mean Blood-Lead Concentration for Pre- and Post-Intervention Measures, by Study Group (Trail Dust Intervention Study).

by 4.2 μg/dL in 10 comparison children between April and September 1993. Comparison children and homes were in the same neighborhoods as the treatment homes, but the follow-up study apparently did not assign homes randomly to treatment and control groups.

Other Interventions

Community education, greening, and dust control programs were designed to benefit all children in Trail. Soil abatement was not performed, because recontamination was almost inevitable from the 300 kg of lead per day in smelter stack emissions. However, seeding and planting of public areas with high lead levels was implemented by a civic group. Community dust levels were reduced by spraying magnesium chloride dust suppressant on unpaved alleys and parking areas. In addition, a residential ground cover program implemented in 1993 provided a 50% rebate on cost of materials to householders who covered bare soil with turf, landscape fabric and mulch, shrubs, concrete, or gravel.

Education and case management activities began in 1991 and have evolved over time. Community education efforts focused on contacts with elementary school or daycare administrators, instructors, and students. Individual education and case management services are available to children with elevated blood-lead levels (PbB>15, or PbB>10 for children under 1 year old) who are identified in annual Fall screening clinics. Eligible children receive blood-lead monitoring and in-home educational visits. Since 1994, ground cover materials or cleaning supplies, equipment, and services have been provided, as well. Cleaning services include biweekly cleaning during summer and monthly cleaning the rest of the year, using the methods of the follow-up study.

Geometric mean soil-lead levels did not change significantly between 1989 and 1992 (GM=725, n=19 and GM =713, n=213, respectively). Therefore, the 14% decline in blood-lead concentrations from 1991 to 1992 and the additional 6% decline from 1992 to 1993 may be attributed primarily to the education efforts. The ground cover subsidy program was open to all families who had participated in the 1992 Fall blood clinic who also had bare soil in their yards. The participation rate was 23%, with 44 families completing projects. A follow-up assessment in 1994 found that the ground cover projects were being maintained adequately, however, 12 of the 44 properties had additional bare soil.

The lead loading of house dust may be reduced temporarily by thorough HEPA vacuuming once every six weeks. In fact, carpet dust-lead loading was reduced by approximately 40 percent immediately following the vacuuming. However, with the on-going contamination stemming from the operational smelter, these levels return to “normal” within a few weeks. Vacuuming every six weeks, even accompanied by education, had no effect on children’s blood-lead concentrations. The follow-up study with biweekly cleaning appeared to be successful in preventing some of the expected summer rise in blood-lead concentrations, although the results were not conclusive. The ground cover subsidy program had a 23% participation rate, with 44 families completing projects and maintaining them for at least one year.

In 1991, a 14% decline in the average blood-lead concentration of Trail children aged 6 to 72 months was attributed primarily to the first year of community education and individual case management efforts. However, declines in subsequent years for children whose families received case management intervention for the first time were not as notable as that found in 1991.

3.2.10 New Jersey's Children's Lead Exposure and Reduction Dust Intervention Study

This study (Rhoads et al., 1997, 1999; Lioy et al., 1998) sought to demonstrate the effectiveness of a combined dust control and educational intervention strategy for children with low to moderate blood-lead levels. The study targeted children under 3 years of age residing in Jersey City, NJ, who were at risk for elevated blood-lead concentrations based on three criteria: 1) having a sibling with a previously reported elevated blood-lead concentration greater than 10 µg/dL, 2) high lead contamination in the home, or 3) a measured blood-lead concentration between 8 and 20 µg/dL. A total of 113 children were enrolled in the study and assigned at random to the Lead Group (LG), which was offered biweekly assistance with home dust control and a series of educational sessions about lead, or the (control) Accident Group (AG), which was offered only education and home safety items related to accident prevention. The two groups were very similar with respect to age, initial blood-lead concentration, number of children, education, and the proportion speaking English. Both groups were followed for 1 year. Both blood- and dust-lead measurements were collected during the course of the study.

The LG families received a median of 3 (range, 1-6) one-hour educational sessions and 17 (range, 0-42) cleaning visits. The baseline dust and dust-lead loadings were comparable among the two groups, but by the one year follow-up dust and dust-lead levels were lower in LG homes for floor, sill, and vacuum samples (decreases of 50% or greater for sills and vacuum samples) while the changes in the AG were smaller and inconsistent. There was, however, an unexplained large drop in the lead loading of vacuum samples in the AG group. Therefore, there was a significant difference in the lead loadings between the LG and AG only for window sills.

As shown in Figure 3-16, blood-lead concentrations in the LG group decreased on average from 12.4 µg/dL to 10.3 µg/dL during the first year of the study (17% decline). In contrast, blood-lead concentrations in the AG group increased from 11.6 to 11.7 µg/dL on average during that time (0.9% increase). The difference in the change in blood-lead concentrations between LG and AG children was statistically significant ($p<0.05$). Also, the reduction in blood-lead levels among the LG children was greater the more times their home was cleaned. There was essentially no change in the blood lead levels for the 11 children living in homes cleaned fewer than 10 times, as opposed to a 34% drop (-3.9 µg/dL) seen in the 16 children whose homes were cleaned 20 times or more.

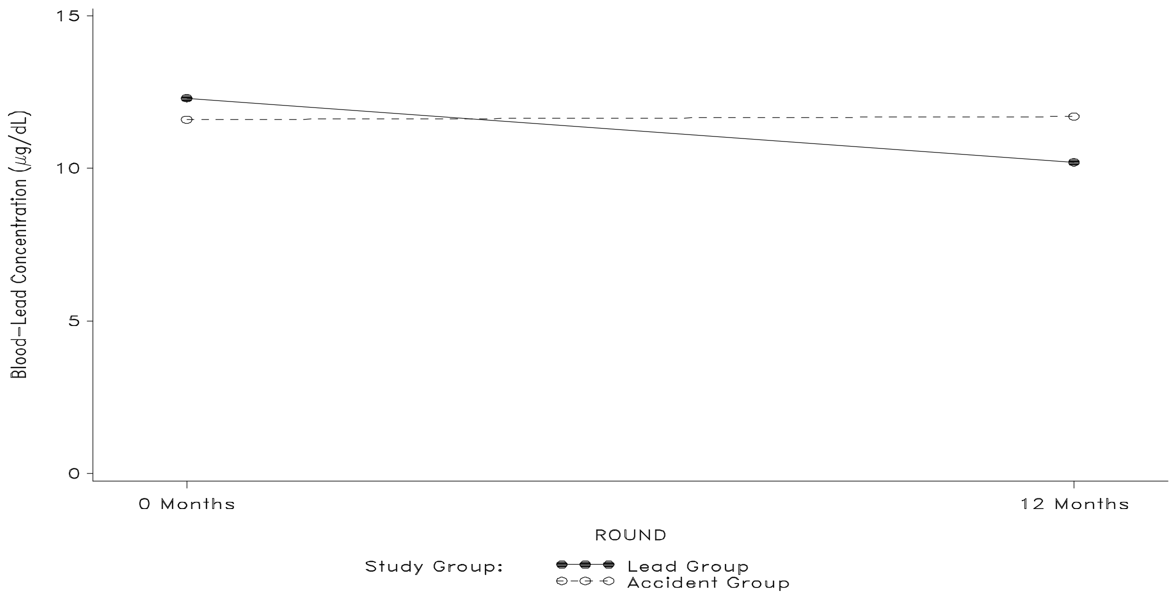


Figure 3-16. Mean Blood-Lead Concentration for Pre-Intervention and Post-Intervention Measures, by Study Group (New Jersey's Children's Lead Exposure and Reduction Dust Intervention Study).

It appears that the combination of biweekly dust control and a series of lead-education sessions was effective in reducing blood-lead levels in this population of children with moderately elevated blood lead levels. The effect of seasonal variation was minimized by taking blood-lead measurements one year apart.

3.2.11 Boston Interim Dust Intervention Study

This study (Aschengrau et al., 1998; Mackey et al., 1996) sought to determine the effectiveness of low-technology lead hazard reductions activities targeting paint and household dust in reducing modestly elevated blood-lead concentrations in children awaiting permanent deleading of household paint in Boston, Massachusetts. Children under the age of four years residing in the city of Boston were selected for possible enrollment. Each child had a venous blood-lead concentration between 11 and 24 µg/dL at enrollment and no history of lead poisoning. In addition, children must have lived in their homes for at least 3 months with no definite plans to move within the next 3 months. The homes must not have been previously deleaded or received lead hazard reduction activities and had lead-based paint on at least 2 window sills and/or window wells. The parents spoke English, Spanish, or Cape Verdean creole as these were the language capabilities of the staff.

Sixty-three of the 402 children eligible for the study were enrolled. The study consisted of three groups. Because of severe household lead hazards, 22 of the children were assigned to an "automatic intervention" group. Severe hazards were characterized as paint chips on any floors, severe amounts of loose dust or paint chips in any window well, or holes larger than one inch wide in walls containing lead-based paint. The remaining 41 children were randomly assigned to the remaining groups, 22 to the "randomized intervention" group and 19 to the "randomized comparison" group. Only 32 of the initial 63 children originally enrolled were included in the blood lead analysis because of absence of follow-up blood samples or their homes received non-study environmental interventions. For the final analysis, the automatic intervention, randomized intervention, and randomized comparison groups consisted of 8, 11, and 13 children, respectively.

For both the randomized and automatic intervention groups, intervention consisted of HEPA vacuuming all window well, window sill, and floor surfaces; washing window well and window sill surfaces with a tri-sodium phosphate (TSP) and water solution; repairing holes in walls; and re-painting window well and window sill surfaces to seal chipping or peeling paint. Both intervention groups also received outreach and educational information including a demonstration of effective housekeeping techniques and monthly reminders with instructions to wash hard surface floors, window sills and wells with a TSP and water solution at least twice a week. The randomized comparison group received only the outreach visit to visually assess the home for lead hazards and to educate the family about the causes and prevention of lead poisoning. They were also provided with cleaning instructions and a free sample of TSP cleaning solution. Dust sample measurements were taken at baseline and 6 months post-intervention for all study groups. Measurements were also taken at one month post-intervention for the two intervention groups, but the results were not reported. Dust samples were taken from floors, window sills, and window wells. Soil, water, and paint samples were taken at baseline. Dust, soil, and water samples were analyzed using atomic absorption spectrophotometry (AAS). Venous samples were obtained to determine blood-lead levels at baseline and an average of six months after intervention. Additionally, trained staff members conducted standardized interviews at enrollment to obtain demographic characteristics, and a 6-month post-intervention visit to assess compliance with housekeeping instructions.

Mean blood-lead levels declined in all three groups 6 months after intervention. For children in the automatic intervention group, mean blood-lead concentrations declined by 48% at 6 months post-intervention. Among children in the randomized intervention and randomized comparison groups, mean blood-lead levels declined by 35% and 36%, respectively, at 6 months post-intervention. Mean blood-lead levels decreased 0.3 µg/dL more in the randomized intervention group and 2.5 µg/dL more in the automatic intervention group as compared to the randomized comparison group (Figure 3-17). At the 6 months post-intervention measure, geometric mean floor dust-lead loadings had decreased slightly for both intervention groups and increased in the comparison group. Geometric mean window sill dust-lead loadings decreased in all three groups, and geometric mean window well dust-lead loadings decreased for both intervention groups, but remained the same for the comparison group (Figure 3-18). None of the changes in dust-lead loadings were statistically significant.

The intervention program appears to have been beneficial to children exposed to severe pre-intervention conditions, but did not have as significant an impact on children with less severe exposure conditions (randomized intervention and comparison groups exhibited roughly the same declines). The one time interventions seemed to have had a small impact on floor dust lead, an intermediate impact on window sill dust lead, and a large effect on window well dust lead. The blood and dust changes should be interpreted cautiously because the sample size was small and none of the results were statistically significant. The magnitude of the reduction in blood-lead levels may be confounded with seasonal variation as sampling occurred at approximately 6 month time intervals.

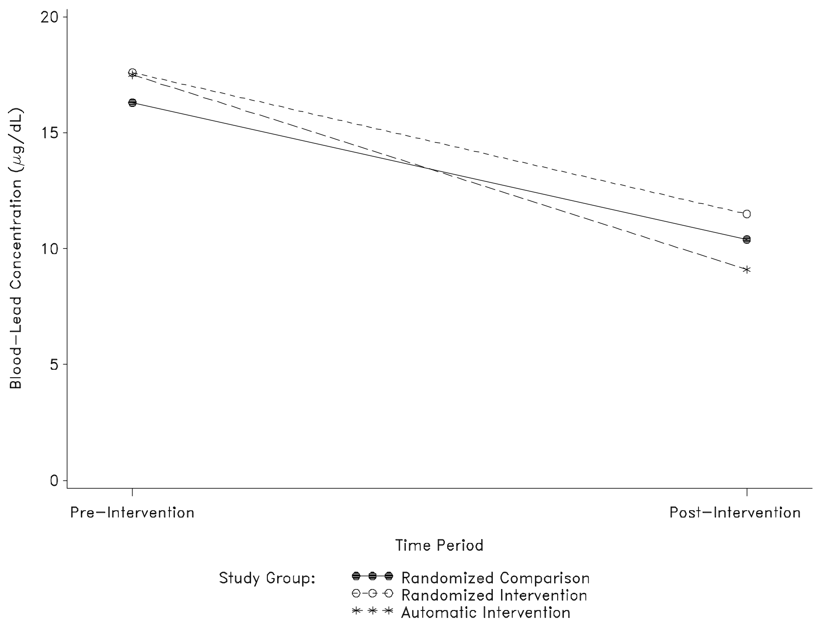


Figure 3-17. Geometric Mean Blood-Lead Concentration (µg/dL) for Pre- and Post-Intervention Measures, by Study Group (Boston Interim Dust Intervention Study).

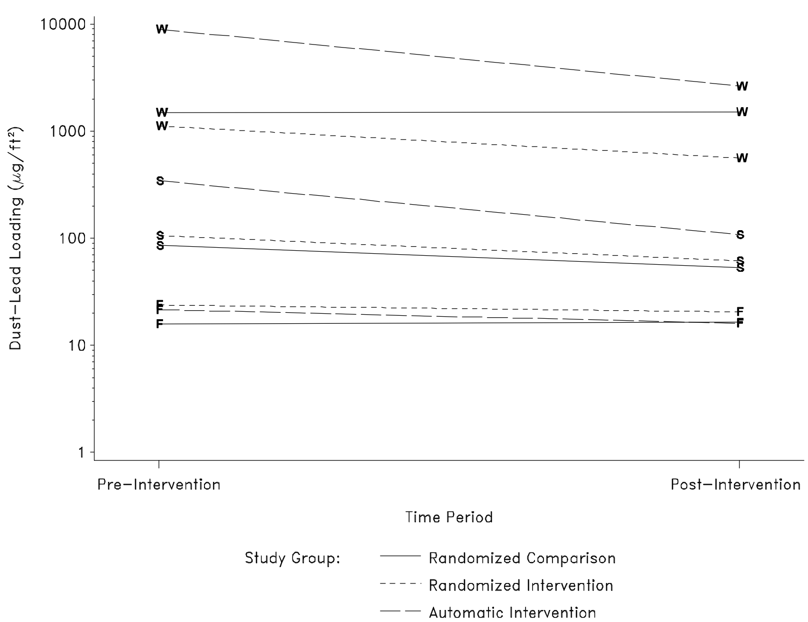


Figure 3-18. Geometric Mean Floor, Window Sill, and Window Well Dust-Lead Loading (µg/ft²) for Pre- and Post-Intervention Measures, by Study Group (Boston Interim Dust Intervention Study).

3.2.12 Rochester Educational Intervention Study

This study (Lanphear et al., 1995, 1996) sought to determine the effectiveness of simple dust control as a means of lowering blood-lead concentrations in children. The study population consisted of 104 urban children, ages 12 to 31 months at enrollment, with low to moderate blood-lead levels. This population was identified and recruited from the 205 children who participated in the Rochester, NY Lead-In-Dust Study. The families of the 104 children were randomly assigned to either the Intervention or the Control Group. A trained interviewer visited families assigned to the Intervention Group at the time of baseline sampling. The importance of dust control as a means of reducing lead exposure was emphasized and cleaning supplies were provided. These included paper towels, spray bottles and Ledisolv, a detergent developed specifically for lead contaminated house dust. Families were instructed to clean the entire house once every three months, interior window sills, window wells and floors near windows once every month, and carpets once a week with a vacuum cleaner, if available. A brochure containing information about lead poisoning and its prevention was provided to families assigned to the Control Group. Baseline measurements of lead in blood, house dust, soil, water, and paint were gathered and follow-up measurements of lead in blood and house dust gathered 7 months later. Blood-lead measurements were collected via venous blood samples. Household dust-lead measurements were collected from entryway floors and the kitchen, as well as from the floors, interior window sills and window wells of the child's principal play area.

Of the 104 children, 95 had follow-up blood-lead measurements available. Only 80 of these 95 lived in the same residence throughout the study period. Differences between baseline and follow-up blood-lead concentrations and between dust-lead levels in the Intervention and Control Groups were tested using (non-parametric) Wilcoxon tests with two-tailed p-values. At baseline, median blood-lead levels were 6.85 µg/dL and 6.10 µg/dL for the Intervention and Control Group, respectively. The post-intervention median blood-lead concentration was 6.20 µg/dL in both study groups (Figure 3-19). The median change in blood-lead levels for the Intervention Group was -0.05 µg/dL, which was not statistically different from the median change of -0.6 µg/dL for the Control group. The median change in blood-lead concentration for 28 children whose families used Ledisolv as instructed (at least once each month) and for the

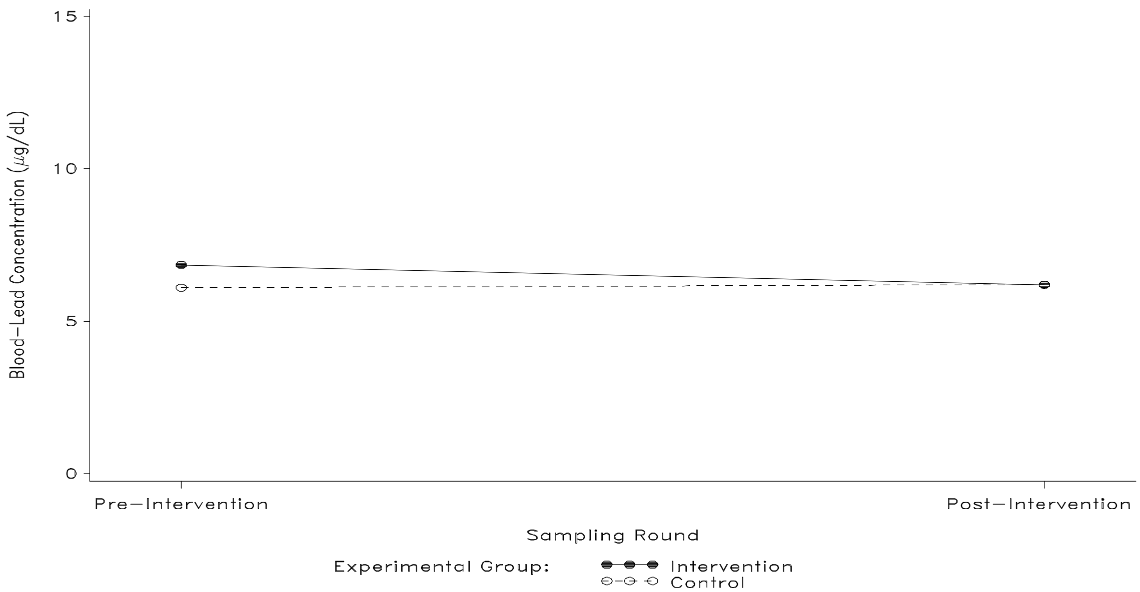


Figure 3-19. Median Blood-Lead Concentration for Pre-Intervention and Post-Intervention Measures, by Study Group (Rochester Educational Intervention Study).

65 children whose families did not use Ledisolv as instructed or were assigned to the control group were also -0.05 µg/dL and -0.6 µg/dL, respectively. Again the difference was not statistically significant. No statistical comparisons of blood-lead levels were made among the subset of 80 children whose families did not move during the course of the study.

Comparisons of pre- and post-intervention dust-lead levels were restricted to homes of children who did not move. The median change in dust-lead levels, averaged across all surfaces, was +45 $\mu g/ft^2$ for the Intervention Group and -67 $\mu g/ft^2$ for the Control Group. For children whose families did or did not use Ledisolv, the median change in dust-lead loading, averaged across all surfaces, was -7 $\mu g/ft^2$ and +2.7 $\mu g/ft^2$, respectively. Neither comparison of dust-lead levels averaged across all surfaces was statistically significant. However, some comparisons of specific areas of homes showed significant or near significant differences by group. The median percentage decrease for dust-lead levels of non-carpeted floors was greater among houses in the intervention group (p=0.08). For families using Ledisolv versus other families, the difference in median change in dust-lead levels on window sills was marginally significant (p=0.07). It was noted that the difference in window well dust-lead loadings at baseline was statistically significant (p=0.05) for these groups.

The results indicate that educational intervention conducted by providing families with simple dust control supplies and information on lead poisoning did not lower blood-lead concentrations for children with low blood lead concentrations more significantly than simply providing families with written information on the hazards and prevention of lead poisoning. Several sources of difficulty include:

1. Since dust control is a simple procedure, families in the Control Group may have taken it upon themselves to implement dust control.

2. It has been shown that vacuuming of lead contaminated carpets may lead to a short-term increase in children's exposure to lead-contaminated house dust (Ewers et al., 1994).

3. It has been shown that blood-lead levels were more significantly reduced following lead hazard intervention for children with higher blood-lead levels than those with lower blood-lead levels. The mean blood-lead concentration for children in this study was lower than that for most other studies.

4. Since declines in blood-lead levels have generally been constant in percentage terms, the power of studies to detect differences will be lower at lower blood-lead levels, unless a very large sample size is studied.

5. The 7-month time span of the experiment may be susceptible to seasonal trends in blood-lead levels. A 12-month time span would minimize the effects of such trends.

It should be noted that a non-parametric approach was taken only after observing that one child in the Control Group, whose mean blood-lead level increased from 14.6 µg/dL to 55.8 µg/dL, increased the change in the mean blood-lead concentration for the control group from -0.55 µg/dL (95%CI = -1.61 to 0.51) without the outlier, to 0.42 with the outlier. The change in mean blood-lead level for the Intervention Group was -0.47 µg/dL (95% CI = -1.21 to 0.27). However, this outlier did not affect the study results enough to have changed the findings.

3.2.13 Baltimore Repair & Maintenance Paint Abatement Study

This study (USEPA, 1995b, 1997, 1998a) seeks to compare and characterize both the short term (2-6 months) and longer term (greater than 12 months) effectiveness of three levels of repair and maintenance (R&M) interventions as a means of reducing childhood lead exposure.

Children with blood-lead concentrations between 10 and 20 µg/dL were of primary interest, as research on intervention strategies for such children is limited.

In January 1993, 75 homes with low-to-moderate monthly rent or mortgage were selected from Baltimore City row houses. Each home was assigned to one of the three R&M intervention groups. The R&M Level I intervention, the least expensive and extensive intervention strategy, included wet scraping of deteriorating lead-based paint on interior surfaces, limited repainting of scraped surfaces, installing entryway mats, wet cleaning and vacuuming with a HEPA vacuum, exterior paint stabilization to the extent possible given budget considerations, and occupant and owner education. In addition, cleaning kits for the occupant's own cleaning efforts and the EPA brochure "Lead Poisoning and Your Children" were provided. R& M Level II intervention included, additionally, treatments to make floors smooth and easier to clean, along with window and door treatments that reduce abrasion of lead painted surfaces. R&M Level III intervention further included window replacement, encapsulation of exterior window and door trim with aluminum coil stock and more durable floor and stairway treatments (e.g., coverings).

In addition to the R&M intervention groups, two control groups were utilized. One control group consisted of 16 households residing in older neighborhood housing which had received comprehensive lead-paint abatement (PA) as part of a pilot abatement project in Baltimore between May 1988 and February 1991. The other control group consisted of 16 households residing in modern urban (MU) homes built after 1979 and hence, presumably, free of lead-based paint. The R&M Level III group consisted solely of families that moved into homes unoccupied prior to intervention; the R&M Level II group consisted of both families that lived in the abated homes prior to intervention and those that moved into homes unoccupied prior to intervention; and the R&M Level I group consisted solely of families that lived in the abated homes prior to intervention. Comparisons were based on data for all resident children, regardless of whether they lived in the abated homes prior to intervention.

The 24-month study consists of seven sampling campaigns: Pre-R&M/Initial, Immediate Post-R&M and 2, 6, 12, 18, and 24 months post R&M. Data collected for each campaign may include (venous) blood, interior dust, soil, and water samples, and structured interview questionnaire data. The study population consisted of 127 children at baseline, with a loss of 27 due to moving and a gain of nine via replacement recruiting, for a total of 109 at the 12-month campaign. Newborns were enrolled when they reached the age of 6 months, and a total of 16 had been added as of the 24-month follow-up. The median age of children residing in the study homes ranged from 36 months to 43 months for the five groups at the 12-month follow-up. Blood-lead data for 28 children whose baseline blood-lead concentrations were greater than 20 µg/dL were analyzed separately from data for the 99 children whose blood-lead concentration was in the primary study range of 10 to 20 µg/dL. For children with initial blood-lead levels below 20 µg/dL, geometric mean blood-lead concentrations changed only slightly between the pre-intervention and 24-month campaigns, for all R&M groups. Children with blood-lead concentrations $\geq$ 20 µg/dL tended to show a decrease in blood-lead concentration over time throughout the 24-month period. These decreases were greatest between pre-intervention and the 12-month campaign but were statistically significant also at the 24-month campaign ($p<0.05$) for R&M I, II, and III and PA groups (MU not included because none of the children in this group had initial blood-lead levels greater than 20 µg/dL). In an attempt to characterize the relationship between blood-lead levels and possible influencing factors, several mixed models were fit to the data. These models allowed for comparison of groups at each campaign over time. Principal findings (for children with blood-lead concentrations < 20 µg/dL and controlling for age and season) based on the statistical modeling are: 1) No statistically significant differences in blood-lead levels were found among the R&M groups during the two years of follow-up, except between R&M I and R&M III at 2 months, 2) No statistically significant changes in blood-lead concentrations were found for the PA control group during the two years of follow-up, and 3) Children in MU houses had statistically significantly lower blood-lead levels than those in the other four groups. Figure 3-20 presents the model predicted geometric means for each campaign.

Dust-lead loading levels decreased from pre-intervention levels for all R&M groups. The geometric mean, based on weighted averages of floor, entryway, window sill, and window well samples, decreased from 17,542; 25,214; and 478,500 µg/ft^2 at the Pre-Intervention/Initial campaign to 2,364; 1,252; and 176 µg/ft^2 at the 24-month campaign, for Level I, II, and III R&M groups, respectively.

The lack of change in the geometric mean of blood-lead concentrations for all five groups could be a result of the fact that initial blood-lead levels were already at low to moderate levels or

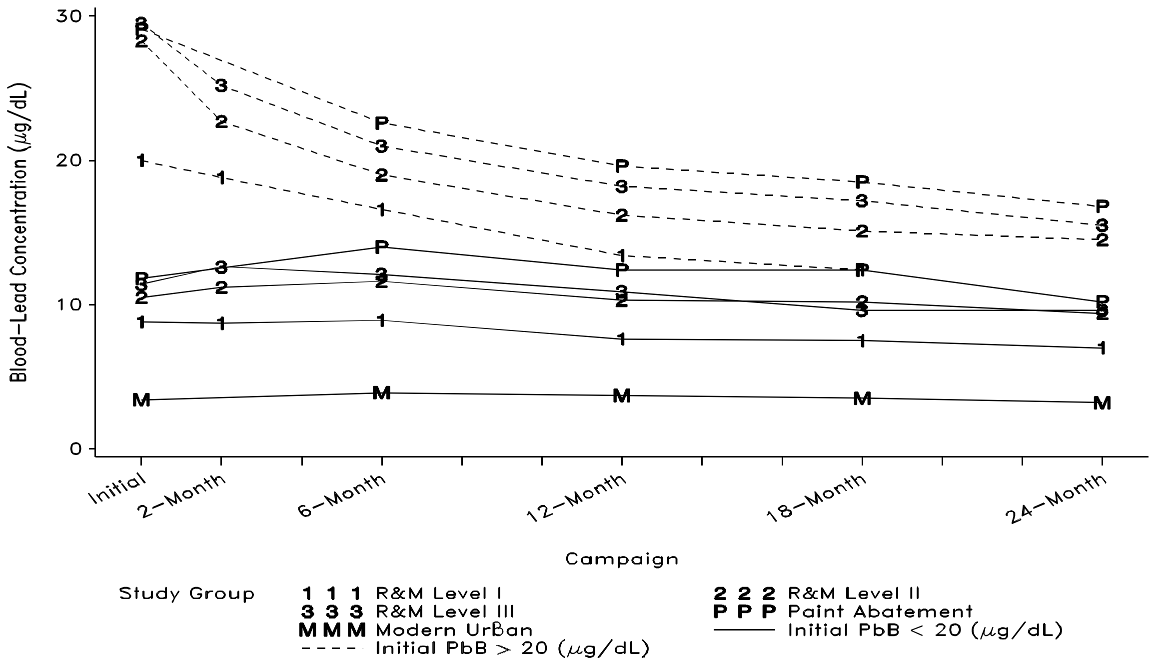


Figure 3-20. Geometric Mean Blood-Lead Concentration at Each Sampling Campaign, by Study Group and Initial Blood-Lead Concentration (Baltimore Repair & Maintenance Paint Abatement Study).

the children's cumulative body lead burdens may have mediated the response. Comparisons were made based on group assignment, regardless of whether or not the child lived in the abated home prior to intervention. All R&M Level I children lived in the same home prior to intervention, while all R&M Level III children did not move in until after invention. Thus, it is not clear whether changes in blood-lead levels were due to pre-intervention residence or due to group assignment. Apparently, this possible confounding factor was in part controlled by comparing children with similar baseline blood-lead levels. It is worth noting that children with baseline blood-lead concentrations greater than 20 µg/dL showed declines in blood-lead levels over time, while children with baseline levels below 20 µg/dL tended to remain below 20 µg/dL. Although decreases in blood-lead concentration were statistically significant at the 24-month campaign, for children with baseline blood-lead concentrations greater than 20 µg/dL in the R&M I, II, III, and PA groups, any conclusion should be made with caution as the sample size of such children for each group was small (n=0,8,7,11 and 9 for MU, PA R&M I, II and III groups, respectively).

3.2.14 New Zealand Retrospective Paint Abatement Study

This study (Bates et al., 1997) sought to identify risk factors for elevated blood lead levels in children, particularly which lead paint removal and clean up practices pose the greatest risk. The sampled population was children aged 12-24 months from Wellington, New Zealand, living in homes more than 50 years old where interior or exterior paint removal had taken place in the last two years. The paint removal was performed by either the resident, friends of the resident family, or a contractor; and methods used were chemical stripping, scraping by hand, various types of sanders, electric heat guns, waterblasting, and blowtorching. To be eligible, the child must have been living in the residence for at least six months. A total of 187 children were identified as eligible, 141 of these children participated in the study.

Blood samples were taken from the children, dust samples were collected from the kitchen, and a questionnaire was administered to the caretaker regarding the general health of the child and parental hobbies.

The overall geometric mean blood-lead level for the children in the study was 5 µg/dL. High blood-lead levels were defined as those $\geq$ 7.2 µg/dL and low levels as < 7.2 µg/dL. It was found that significant differences in blood-lead levels existed with regard to income, with higher income being associated with lower blood-lead levels. Parental hobbies like making stained glass or lead lighting, or making lead shot or ammunition were associated with elevated blood-lead levels. Interior and exterior paint abatement data were analyzed separately, and it was found for both that the differences in blood-lead levels were not significant for any particular paint removal method except blow torching. This method was also associated with significantly higher blood-lead levels when performed by the resident or friends, as opposed to contractors. Figure 3-21 shows the geometric means and percentage of children with high blood-lead levels for each paint removal method examined. None of the clean up or disposal methods examined were associated with high blood-lead levels.

The major purpose of this study was to identify specific paint removal and clean up practices that were associated with children's elevated blood-lead levels. None of the methods were identified as hazardous in terms of blood-lead levels, except for high-temperature methods, which have been known to be risky for some time. Chemical stripping is, of course, potentially hazardous due to the chemicals involved, but was not associated with elevated blood-lead levels

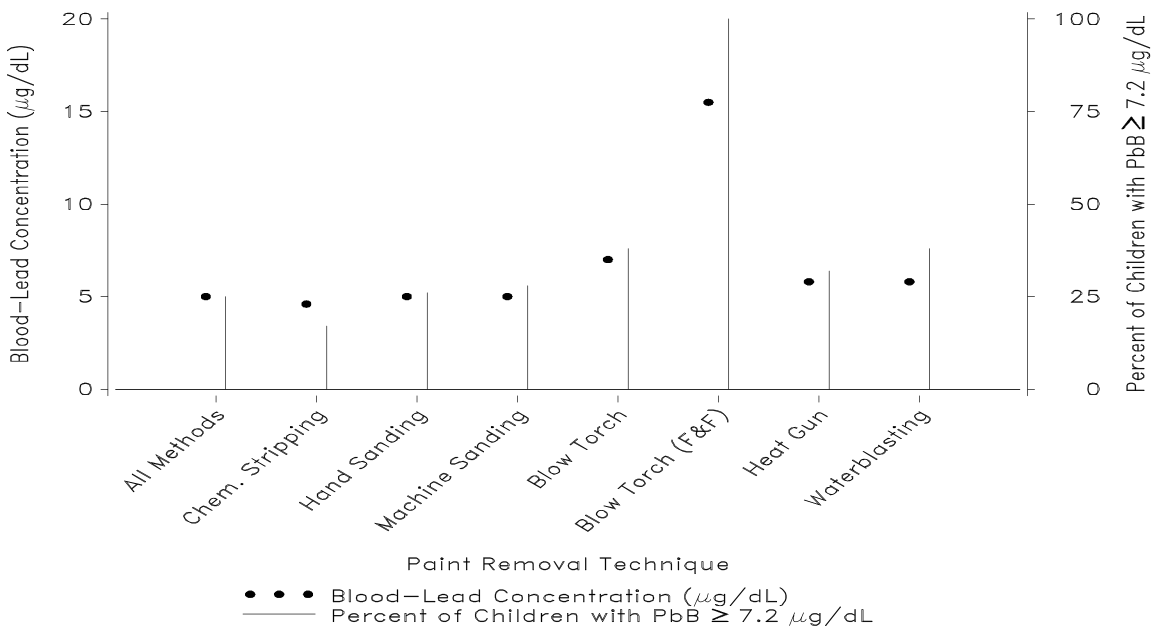


Figure 3-21. Geometric Mean Blood-Lead Concentration and Percentage of Children with Blood-Lead Concentration ≥ 7.2 µg/dL, by Paint Removal Technique (New Zealand Retrospective Paint Abatement Study).

in this study. The authors also noted that there were a number of weak, non-statistically significant results that suggested abatement work performed by family and friends is more likely to be associated with elevated blood-lead levels than work done by contractors. This result could be due to selection bias, as 30% of the contractors were not available to be interviewed about the work they performed. Another notable result was the association of elevated blood-lead levels with several parental hobbies. However, this apparent association is confounded with the fact that two of the four children whose parents were engaged in “risky” hobbies also lived in the homes where high-temperature abatement methods had been used. Since the number of families with hobbies involving lead was quite small, it was impossible to assess the relative importance of these factors.

3.2.15 East St. Louis Educational Intervention Study

This study (Copley, 1995, 1996) sought to determine whether an educational intervention, which provided in-home instruction and identification of problem areas, could be successful in reducing household dust-lead levels in a low socio-economic status, multi-ethnic community. Most residents of this predominantly African-American community receive some form of public assistance. Children, with blood-lead concentrations between 10 and 19 µg/dL, were identified through a screening program for children receiving public assistance. Fifty-four homes were included in the study. These households consisted of approximately 124 young children and 117 adults.

During the initial visit, an XRF paint survey was conducted and areas with high lead loadings were pointed out to the residents. Lead educators, hired from within the community, provided instruction on cleaning and hygiene. Written materials and a videotape on reducing lead exposure were also provided. Participating families were contacted regularly throughout the course of the study to reinforce the importance of regular, thorough cleaning. Environmental samples were collected at the initial visit. Three-month follow-up samples were collected in homes where the residents reported that they had cleaned at least once using the recommended procedures. No control population was evaluated, nor were follow-up samples collected in homes where residents did not clean.

After repeated follow-up calls only 24 of the 54 families reported that they had cleaned at least once during the three months using the recommended procedures. A total of 1,166 surfaces were tested for lead-based paint in the 55 homes, of which 197 exterior and 145 interior surfaces tested positive. In addition to lead paint surveys, dust samples were collected from 164 smooth surfaces and from 69 carpets. Of the 164 smooth surfaces tested, 75 samples were below the detection level of 5 µg/ft^2, and 46 of the remaining 89 samples had dust-lead levels greater than 200 µg/ft^2 (Illinois clearance standard). Comparison of lead dust concentrations prior to cleaning and after at least one conventional cleaning effort revealed a 56 percent decrease in the arithmetic mean dust-lead loading (Figure 3-22). Mean floor dust-lead loadings decreased from 1095 µg/ft^2 to 486 µg/ft^2 while the geometric mean decreased from 454 µg/ft^2 to 58 µg/ft^2 for the 30 smooth surfaces which had been cleaned at least one time by the residents. The mean carpet dust-lead

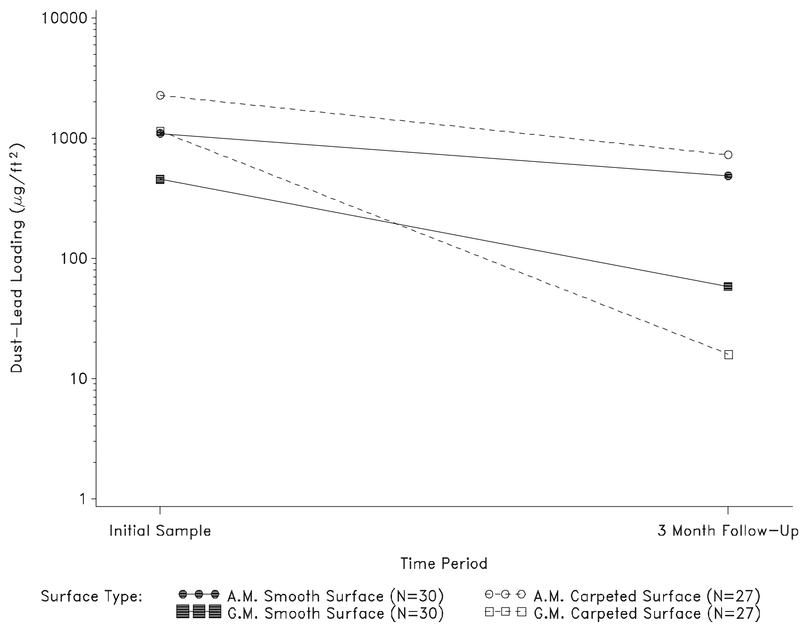


Figure 3-22. Changes in Arithmetic and Geometric Mean Dust-Lead Loadings (µg/ft²) by Surface Type and Sampling Round (East St. Louis Educational Intervention Study).

loading decreased to 725 µg/ft² from 2,268 µg/ft² and the geometric mean declined to 16 µg/ft² from 1,143 µg/ft² at the three-month follow-up measure.

This study suggests education and residential cleaning by the homeowner can be effective in reducing dust-lead levels in the home, thereby potentially reducing children's lead exposure. However, educational interventions rely on the initiative of the family to implement the recommended procedures. In this community, many families did not follow through with the procedures; consequently, their children may not have benefitted from the educational intervention. Because follow-up blood-lead measures were not collected and no control population was evaluated, the effect of the intervention on children's blood-lead levels cannot be assessed.

3.2.16 HUD Abatement Grant Program

This ongoing study (NCLSH and UC, 1997; 1998) seeks to determine the effectiveness of the various abatement methods used by State and local government HUD grantees to reduce lead-based paint hazards in housing. Eighty-three state and local government agencies are participating in the HUD Lead-Based Hazard Control Grant Program (HUD Grantee) and 14 out of the 83 grantees are participating in the formal evaluation of the program. Each grantee is responsible for designing a program applicable to its specific needs and objectives; including how dwellings are enrolled. Thus, enrollment criteria varied among the different grantees and included targeting high-risk neighborhoods, enrolling only homes with a lead-poisoned child, and considering unsolicited applications. The grantees also have the flexibility to select the type and intensity of the lead treatments for any particular unit. The interventions selected ranged from taking no action in an area or simple cleaning, to window replacement or full lead-based paint abatement. The grantees all follow the same sampling protocols when collecting the data, and use standard forms developed specifically for the evaluation. Information is gathered four times during the study: prior to intervention, immediately after intervention, and 6 and 12 months after intervention. In addition, nine grantees will collect data at 24 and 36 months after intervention for approximately 750 dwelling units.

Across all grantees there are currently 3,556 enrolled dwellings (of which 2,900 will be part of the formal evaluation), 2,432 enrolled households, and 1,933 enrolled children under age six. Through September 1, 1997, interventions had been completed in 2,297 of the 2,900 enrolled dwelling units. Information on the interior strategies was available for 1,506 units, and current results indicate that 69% of the units have received extensive treatments that include partial or complete replacement of windows rather than lower level interventions like specialized cleaning and the stabilization of deteriorated paint. Either no interior work or full abatement of the lead hazards was conducted in fewer than 4% of the units.

Information on exterior strategies was available for 810 buildings. In about 16% of these no action was taken, and approximately 9% had full abatements performed. The majority of grantees chose to perform mostly (60%) partial or complete stabilization of lead-based paint. Of the 787 buildings with site/soil strategies reported, 686 (87%) received no soil treatment. When a site intervention was performed, it was most commonly a low level strategy like providing soil with a temporary cover such as mulch, although a small percentage of higher level treatments, including total soil removal, have been performed.

Dust sampling results are reported for occupied dwellings, where the effectiveness of lead interventions can be examined without the confounding effects of vacancy (vacant residences have been estimated to have higher dust-lead loadings). The changes in dust-lead loading from pre-intervention (phase 1) to immediate post-intervention (phase 2), six months post-intervention (phase 3) and twelve months post-intervention (phase 4) are presented for floors, window sills, and window troughs in Figure 3-23. Dust-lead loadings from Phases 1 -3 for floors were available from 892 occupied dwellings, and while interventions were found not to have much impact on the median dust-lead loading (20 $\mu g/ft^2$ pre-intervention and 18 $\mu g/ft^2$ immediately after), they did appear to greatly reduce levels at the upper end of the distribution. For example, the 90th percentile floor dust-lead loading was reduced by 67% from 150 down to 50 $\mu g/ft^2$. The reported changes in the median level may have been limited by the analytical limits of detection. At 6-month post-intervention (phase 3) median levels had declined further, with a decrease from 18 $\mu g/ft^2$ in phase 2 to 14 $\mu g/ft^2$ in phase 3, and an overall decrease of 30% from phase 1. Twelve-month post-intervention data were available for 557 units and showed little evidence of reaccumulation between phase 3 and 4. Also, phase 4 levels remained well below pre-intervention levels with an overall decrease of 26%.

Phase 1 through 3 dust-lead loadings for interior window sills were available for 877 occupied dwellings and there was an 82% decline in the median loading from phase 1 to 2. In contrast to the results from the floor lead loadings, window sill lead loadings had a tendency to rise from phase 2 to phase 3 in the available data. However, because of the large reduction in levels from phase 1 to phase 2, the phase 3 loadings are still substantially lower than pre-intervention levels (68% decline). Twelve-month post-intervention (phase 4) data were available for 547 units and showed a slight decrease in the dust-lead loadings from phase 3 to phase 4. However, the declines were fairly small and well within the margin of error of the dust wiping protocol.

Dust-lead loadings for window troughs from Phases 1-3 were available for 731 dwellings and there was a substantial (99%) decline in the median levels, as well as in the low and high ends of the distribution. Window troughs showed a greater tendency toward reaccumulation than

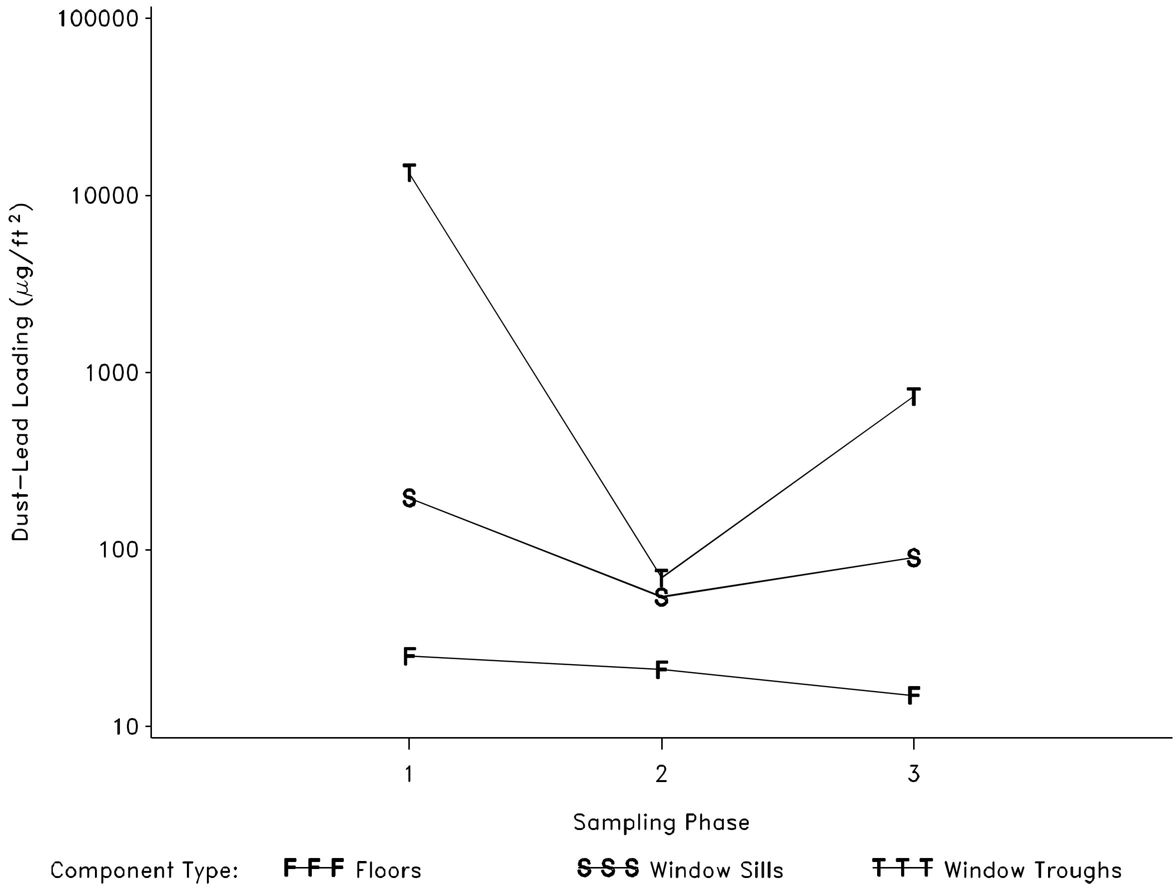


Figure 3-23. Median Dust-Lead Loading on Floors, Window Sills, and Window Troughs for Units where Data were Reported at Pre-Intervention (Phase 1), Immediate Post-Intervention (Phase 2), 6-Months Post-Intervention (Phase 3), and 12-Months Post-Intervention (Phase 4) (HUD Abatement Grant Program).

window sills between phase 2 and 3, with the median trough loading increasing more than tenfold (from 54 µg/ft^2 to 603 µg/ft^2). Despite this increase, the phase 3 levels were still significantly lower than pre-intervention levels with an overall decrease of 95%. In the 448 units with phase 4 data, an unexpected decline was seen in the dust-lead loadings between Phases 3 and 4. This result warrants further investigation due to possible effects of the study design that cannot yet be ruled out.

Results were presented as well for the clearance testing that was required after the interventions were completed. Overall, 28% of the units failed to pass clearance for at least one component on the first attempt. Initial clearance failure rates varied among the grantees, with

Rhode Island reporting an 8% failure rate, 5 additional grantees reporting approximately 20% failure rates, and 7 grantees reporting failure rates from 36 to 50 percent. Overall, the initial clearance failure rate for floors (18%) was higher than those reported for window sills (8%) or troughs (10%).

Pre-intervention (phase 1) and 6-month post-intervention (phase 3) blood-lead results were available for 541 out of the 1,933 children under age 6 enrolled and are presented in terms of the number of children whose phase 1 and phase 3 blood-lead levels were the same (<3 µg/dL difference), had a "small" difference (>3 µg/dL to 6 µg/dL), or had a "large" difference (>6 µg/dL). The blood-lead changes were adjusted to reflect the expected changes due to the time of year (season) and the child's age. The percentage of children who had no change (defined as <3 µg/dL due to measurement error) in adjusted blood-lead levels was approximately 59%. About five times as many children had "small" decreases (18%) than had "small" increases (3.5%), and approximately four times as many had "large" decreases (16%) than had "large" increases (4%). Twelve-month post-intervention data was available for 338 children and approximately 50% had no change, six times as many had "small" decreases than increases, and ten times as many had "large" decreases than increases.

This study is one of the largest and most comprehensive ever initiated with data collection beginning in 1994 and continuing until 1999. Since the analysis of these data will continue beyond 1999, results presented at this time should be considered preliminary. Also, an ideal research project designed to test the effects over time of environmental intervention techniques on dust-lead and blood-lead levels would have a randomly selected group of units to be treated, and a control group that is similar. However, such research strategies were not compatible with the program. Therefore, some additional data was collected so changes in lead levels could be determined to be the result of the lead hazard control work and not other factors. Even so, the findings from the evaluation will have to be interpreted carefully and causal relationships that may be implied by the results will require confirmation in a more controlled investigation.

In terms of dust-lead loading, the interventions performed seem to be very effective at immediately reducing window sill and trough dust-lead levels and very high floor dust-lead levels. The effect on the median floor dust-lead level was not apparent, and could be due to the fact that the pre-intervention levels were relatively low. Reductions at low levels may commonly be underestimated, as laboratories have limits on how much leaded dust can be detected. Floors showed little reaccumulation of lead dust through six months post-intervention, and while some lead dust did reaccumulate in the window sills and troughs, there was still a net reduction in dust lead from pre-intervention levels. These results suggest that the interventions are reducing one of the largest sources of exposure for children, and that the benefits of the interventions are greatest in homes and on surfaces with the highest levels of contamination. It was also found that 28% of units did not pass clearance on the first try. This reinforces the importance of performing clearance tests and suggests that a further analysis of the causes of failure are needed. Failures can have a substantial financial impact due to the cost of re-cleaning and re-testing the dwelling and continued relocation of the families. Understanding the cause of the failures can help to prevent and avoid these costs.

Changes in blood-lead levels are not considered the primary outcome measure in this study because they are susceptible to so many factors. At six months post-intervention, 59% of the children had blood-lead levels that were essentially the same as their pre-intervention level. This result is not surprising as many of the enrolled children were previously exposed to lead and may have had high internal body stores of lead. For such children, blood-lead levels may change very slowly, even if the source of lead exposure is eliminated. However, for the children whose blood-lead levels did change, there were almost five times as many decreases than increases at 6-months post-intervention, and eight times as many decreases than increases at 12-months post-intervention.

3.2.17 Canadian Community-wide Approach (3 Studies)

Three studies are summarized together in this section. These studies (Langlois et al., 1996; Goulet et al., 1996; Gangne, 1994) document community wide abatement programs instituted in three Canadian cities following the reduction or elimination of industrial emissions. These studies are summarized together because of similarities in the programs and because the targeted lead source was industrial rather than residential lead-based paint. These studies are relevant, however, because the intervention methods employed are similar to those used to address lead-based paint hazards.

The three Canadian study sites were the South Riverdale suburb of Toronto (Langlois and Gould, 1996), St-Jean-sur-Richelieu (SJR) in Quebec (Goulet et al., 1996), and the Notre-Dame district of Rouyn-Noranda (RN), Quebec (Gaugne, 1994). The Toronto and SJR studies reported community-wide abatement programs that removed lead-contaminated soil and house dust from most homes in the community. A community-wide soil abatement program was implemented in RN. In addition, public education was a component of the SJR and RN studies. In SJR, the source of the lead hazard was completely removed by closing and permanently covering the site of a battery reclamation plant. The Toronto and RN sites had continued, but reduced, lead emissions from active secondary lead and copper smelters, respectively. All three studies selected homes based on their proximity to the industrial source. All three studies assessed program effectiveness through community screening programs with high participation rates. Greater detail is provided in separate abstracts of these studies in Appendix A (A.17a, b, and c).

In Toronto, soil abatements were performed between May and October 1988 for nearly all of the approximately 970 properties in South Riverdale that qualified for the soil abatement program. Professional housecleaning services were offered to all 1,029 households in the study area, regardless of soil-lead level. Cleaning was performed between April and November 1989 for the 717 (69.7%) households that accepted this service. Blood-lead concentrations decreased over time in all study groups. Two control groups were utilized in this study: a sociodemographically similar group of South Riverdale children who did not live near the smelter and a sociodemographically dissimilar group of Toronto schoolchildren. Although the study area had higher blood-lead concentrations than the control areas prior to abatement, by 1992 the geometric mean blood-lead concentration was no longer significantly greater than control means. Geometric mean blood-lead concentrations in the study area were 10.9 μg/dL in 1987 (pre-abatement), 9.3 in 1988 (during abatement), 6.4 in 1990 (post-abatement), and 3.9 in 1992 (post-abatement) (Figure 3-24). Geometric mean blood-lead concentrations in the South Riverdale control area were 7.1 μg/dL in 1988 and 4.2 μg/dL in 1990. Geometric mean blood-lead concentrations in the Toronto schools control group were 5.1 μg/dL in 1988, 3.6 in

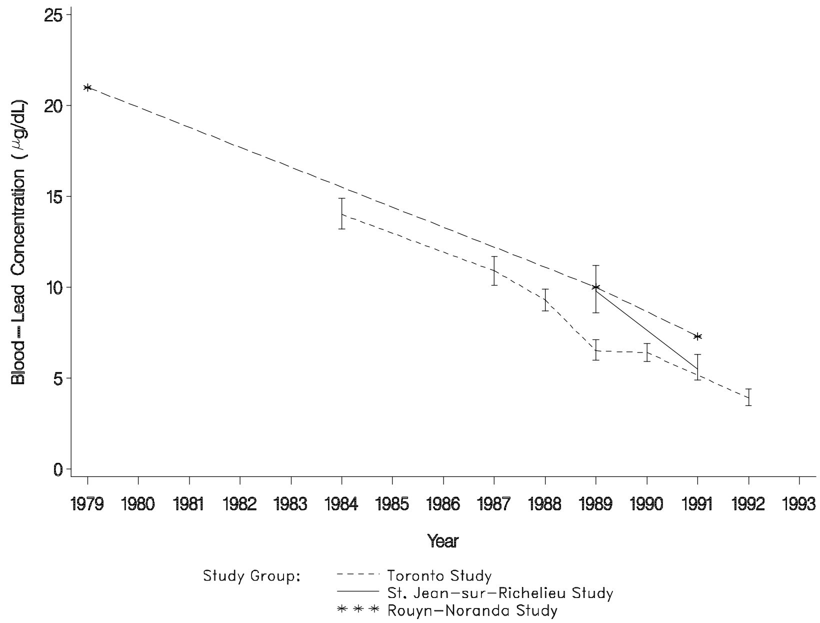


Figure 3-24. Geometric Mean Blood-Lead Concentrations in Three Communities over Time (Canadian Community-wide Approach (3 Studies)).

1990, and 3.5 in 1992. In 1987, 57% of children in the study area had blood-lead levels greater than 10 μg/dL. In 1992, only 7% of children had blood-lead levels above 10 μg/dL.

Several additional analyses were conducted using blood-lead data from the study area. For these analyses, children were categorized into one of four abatement groups: (a) soil abatement, (b) dust abatement, (c) both soil and dust abatement, and (d) no abatement. Multiple blood-lead measurements from 160 children (415 samples) and single measurements from 500 children were analyzed together, under the implicit assumption that all measurements were independent. On average, throughout the study period, children with no abatement had the lowest blood-lead concentrations. In addition, blood-lead concentrations of children with no abatement declined more rapidly than those in the abatement groups. This result was seen consistently across several statistical models considered by the authors. Because the blood-lead screening took place while abatements were ongoing, comparisons were made between children who had received the abatement and those who had not yet received the scheduled abatement. No significant differences were reported for these comparisons.

The validity of these results is unclear, since multiple, positively correlated measurements over time from some children were treated as independent measurements. Within the study area, 45% of the data were not independent. The authors suggest, based on a sensitivity analysis, that selection bias could explain some of the differences in trends among the abatement groups. Although multiple blood-lead measurements were available, no attempt was made to assess the effect of the intervention using pre- and post-intervention measures from the same children.

In SJR, intervention activities included asphalting the plant yard, removing dust from the roads and sidewalks, removing and replacing the contaminated soils, professional house cleaning, and implementing a public health-education campaign. The geometric mean blood-lead concentration was reported for children who had participated in both the 1988 and 1991 screenings. The geometric mean blood-lead concentration for children 6 months to 10 years of age (n=75) dropped from 9.7 µg/dL in 1989 to 5.0 µg/dL in 1991. The geometric mean blood-lead concentration for children aged 6 months to 5 years decreased from 9.8 µg/dL to 5.5 µg/dL. These differences were statistically significant ($p<0.0001$). In 1991, none of the children had blood-lead levels of 15.0 µg/dL or greater; whereas in 1989, 21.3% of the children were in this category. Two oral behaviors also changed significantly between 1989 and 1991. In 1989, pica was present in 35.5% of the children, but by 1991, this percentage had declined to 18.8% ($p=0.004$). In 1989, 46.2% of the children put things in their mouths, compared to 31.7% in 1991 ($p=0.03$).

In RN, the Notre-Dame district is located within one kilometer of a 2,500 ton/day copper smelter. Between 1979 and 1989, stack emissions were lowered by 50%. In 1990-91, it was decided that all residential lots with greater than 500 mg/kg (ppm) soil lead levels would be decontaminated and that from 1992 to 1995 air lead levels would be further reduced. Soil abatement was completed in August 1991, with 80% of the 710 residential lots in the district abated. From 1979 to 1989 the district geometric mean blood-lead concentration dropped from 21 µg/dL to 10 µg/dL in two to five year old children. However, in 1989 50% of all children still had blood-lead concentrations above 10 µg/dL. By 1991, the geometric mean blood-lead concentration had declined to 7.2 µg/dL for one to five year old children. Also in 1991, only 25% of the children had blood-lead concentrations above 10 µg/dL and none had concentrations greater than 20 µg/dL.

All three Canadian communities attained the primary objective of lowering the mean blood-lead level of children who lived within the contaminated area. Although the Toronto study area had higher blood-lead concentrations than the control areas prior to abatement, by 1992 the mean blood-lead concentration in the study area was no longer significantly different from the Toronto schools control mean. While no control population was available in St-Jean-sur-Richelieu, similar geometric mean blood-lead levels were observed in 1991 between children who had lived in the area in 1989 and new residents (presumed to have no unusual lead exposure) 6 months to 10 years of age. This was a comparable result to the Toronto study. Blood-lead concentrations showed a lesser decline in Rouyn-Noranda, where dust abatements were not part of the intervention strategy and lead emissions from the local smelter continued during the time of the study.

4.0 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, 1998b; CDC, 1991, 1997; ATSDR, 1988).

The hand-to-mouth exposure pathway may be disrupted by abatement or interim control methods. Abatement methods include a variety of methods that remove the lead source, or permanently cover it. In contrast, interim controls include paint stabilization (removal only of deteriorated lead-based paint), abatement of lead-containing dust, and covering bare soil with mulch or grass. These methods typically do not remove the lead source. Interim control interventions have been studied alone and in combination with abatements. For example, paint stabilization or dust control measures were implemented along with soil abatement in the “Three City” soil abatement studies. Other studies have assessed the effectiveness of one-time or regular cleaning by professionals using HEPA vacuums and wet wash. Interim control methods are attractive because of the low up-front costs of interim controls relative to many abatement techniques. However, because the source is not removed, the long-term cost of maintaining interim controls may exceed the cost of abatement. In addition, there is evidence that recontamination occurs quickly when regular cleaning is discontinued. A discussion of studies that assess abatement and interim control strategies follows in Section 4.1.

Educational interventions target the hand-to-mouth pathway indirectly. These interventions typically seek to educate family members on the sources of lead in the home and emphasize the importance of regular cleaning and good hygiene in reducing lead exposure. The interventions studied have been as simple as providing a brochure on lead-poisoning prevention, or may have consisted of an in-home visit during which cleaning techniques are demonstrated and problem areas identified. Educational interventions are often implemented as a component of a studied abatement or interim control strategy, but have been evaluated independently. It should be noted that when education is the primary intervention strategy, the intervention relies on the initiative of the individual to follow through with recommended procedures and each new occupant must receive the educational intervention. Studies that assess educational intervention as the primary intervention strategy are summarized in Section 4.2.

The targeted sources of lead and types of interventions employed in each study are summarized in Table 4-1. Summary tables of blood-lead concentration results and other body-lead burden results are presented in Appendix B, Tables B-1 and B-2, respectively. Summaries of efficacy with respect to environmental lead measures are presented in Table B-3 and in Appendix E. Tables 4-1, B-1, B-2, and B-3 and the sections that follow include both the studies summarized in the previous report and the additional studies summarized in this report.

4.1 ABATEMENT AND INTERIM CONTROL INTERVENTIONS

Six of the studies summarized in this report targeted lead-based paint hazards. These additional studies reinforce conclusions drawn previously about paint abatement. Namely, paint abatement is effective in reducing blood-lead levels of children above 20 μg/dL, but may not be as effective for children below 20 μg/dL, at least in the short term as a secondary prevention measure. Also, improperly performed abatements may lead to increases in blood-lead concentrations.

In New York (Markowitz et al., 1996), a combined strategy of paint abatement, education, and iron therapy resulted in a 27% decline in blood-lead concentrations in children with elevated (25-55 μg/dL) blood-lead levels. This study used a home environment score (HES), based on condition of paint and lead content, to evaluate the extent of the lead hazard in each home. As expected, children whose HES scores indicated greater lead hazards had higher pre-intervention blood-lead concentrations. By 6 months post-intervention, however, two-thirds of the children had blood-lead levels below 25, regardless of the initial HES. HES scores declined during the study, indicating that interventions took place. By week 24, 20% of homes had an HES score of 0, indicating no lead hazard remained. In Paris (Nedellec et al., 1995), a combination of chemical stripping, encapsulation, and component replacement strategies was used to abate 59 homes, resulting in a 40% decline in floor dust-lead loadings 1-2 months post-abatement. In follow-up sampling conducted 6-28 months post-abatement, maximum floor dust-lead loadings remained below 100 $\mu g/ft^2$. Blood-lead levels of 74 of 78 resident children declined significantly, but the actual levels were not reported. Similar results were reported by

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

Primary Targeted Lead Source	Study Title	Intervention Strategy: Abatement			Interim Controls		Abatement Included Extensive Clean-Up	Sources Abated			Blood-Lead Measures Collected	Control Group
		Encap / Enclo	Cmplt Rmvl	Partial Rmvl	Home-owner	Profes-sional		Soil	Dust	Paint		
Paint	1982 St. Louis Retrospective	M		M						M	M	
	Baltimore Traditional/Modified			M						M	M	
	Boston Retrospective	M		M			M			M	M	
	Baltimore Experimental	M	M				M			M		
	New York Paint Abatement			M						M	M	
	Central Massachusetts Retrospective	M		M			M			M	M	
	1990 St. Louis Retrospective	M		M						M	M	M
	HUD Demo Study	M	M				M			M		
	CAP Study	M	M				M			M		M
	Milwaukee Retrospective LBP			M						M	M	
	New York Chelation			M						M	M	
	Paris Paint Abatement	M	M				M			M	M	
	Baltimore Follow-up	M	M				M			M		
	Baltimore R&M	M		M	M		M		M	M	M	M
	New Zealand Retrospective		M							M	M	
	HUD Abatement Grant Program	M	M	M		M	M	M	M	M	M	

Table 4-1. Summary Information for Identified Lead Hazard Intervention Studies (continued)

Primary Targeted Lead Source	Study Title	Intervention Strategy: Abatement: Encap / Enclo	Intervention Strategy: Abatement: Cmplt Rmvl	Intervention Strategy: Abatement: Partial Rmvl	Intervention Strategy: Interim Controls: Home-owner	Intervention Strategy: Interim Controls: Profes-sional	Abatement Included Extensive Clean-Up	Sources Abated: Soil	Sources Abated: Dust	Sources Abated: Paint	Blood-Lead Measures Collected	Control Group
Dust (Cleaning)	Baltimore Dust Control[1]		M	M		M			M	M	M	M
	Seattle Track-In				M				M			
	Minneapolis Dust Intervention[1]		M	M		M			M	M	M	M
	Trail Dust Intervention		M		M	M			M		M	M
	NJ CLEAR		M		M	M			M		M	M
	Boston Interim		M		M	M			M		M	M
Dust (Education)	Milwaukee Retrospective Educ.				M				M		M	M
	Granite City Educational				M				M		M	
	Milwaukee Prospective Educ.				M				M		M	
	Leadville/Lake County Educ.				M				M		M	
	Rochester Educational				M				M		M	M
	East St. Louis Educational				M				M			
Soil	Baltimore 3-City[2]		M	M				M		M	M	M
	Cincinnati 3-City		M					M	M		M	M
	Boston 3-City	M	M	M		M	M	M	M	M	M	M
	Toronto Soil and Dust		M			M		M	M		M	M
	Rouyn-Noranda Soil		M			M		M			M	
	St. Jean-Sur-Richelieu Soil and Dust		M			M		M	M		M	

[1] These residences received partial lead-based paint abatements and complete abatements of lead-containing dust.
[2] These residences received partial lead-based paint abatements and complete abatements of lead-containing soil.

the HUD Abatement Grant Program (NCLSH and UC, 1997; 1998). Declines of 26, 65, and 95% were observed in dust-lead loadings on floors, window sills, and window troughs 12 months post-intervention. Only limited results on blood-lead levels of resident children were reported at this time. A less than 3 μg/dL change in blood-lead concentration was observed in 50% of 338 children, while blood-lead levels decreased by at least 3 μg/dL in 45% of children and increased by that amount in 5%. These are preliminary post-intervention results reported from this large-scale, ongoing study. At the time of the report, interventions had been completed in 79% of the 2,900 enrolled dwelling units, however, data had been compiled for fewer units and resident children.

Additional results reported for the Boston Three-City soil abatement study (Aschengrau et al., 1997) provided an assessment of lead-based paint abatements performed during the second phase of interventions. In this study, blood-lead levels of children who received both lead-based paint and soil abatements in the second phase declined by 20%, while those of children who received soil abatement alone declined 30%. Similarly, blood-lead levels of children who received soil abatement in the first phase declined by an additional 20% in the second year with no additional intervention, while a 4% increase was observed in those who had first phase soil abatement and second phase paint abatement. These results are consistent with those reported in the Central Massachusetts Retrospective Paint Abatement Study (Swindell et al., 1994), where lead-based paint abatement was not effective for a small number of children with initial blood-lead concentrations below 20 µg/dL. The ineffectiveness of paint abatements in the Boston Three-City study may be explained, in part, by the increased dust-lead levels in the homes following paint abatements. While floor dust-lead loadings increased in all study homes during Phase II, greater increases were observed in homes that received paint abatements. Similarly, window sill dust-lead loadings increases or stayed the same in homes that received paint abatements, but declined in homes that did not.

The Baltimore Repair and Maintenance (R&M) Study (USEPA, 1995b, 1997, 1998a) differed from previous studies by targeting children with blood-lead concentrations between 10 and 20 µg/dL and by examining interim control intervention strategies. While the R&M Level I intervention was limited primarily to cleaning and paint stabilization, the R&M Level III intervention was rather extensive, including window replacement and encapsulation of some surfaces in addition to the treatments applied in other study homes, and rivaled paint abatement in cost. Using a statistical model, small declines of 10 to 20% were estimated at 24 months post-intervention in children with initial blood-lead concentrations below 20 μg/dL, for the three levels of R&M interventions and for previously abated homes. It should be noted that the results reported for previously abated homes provide 4 to 6 year follow-up on the abatements performed in these homes. A smaller number of children with initial blood-lead concentrations above 25 µg/dL were included in the study and analyzed separately. For these children, significant decreases in blood-lead concentration were reported at 12 and 24 months post-intervention. After 24 months, dust-lead loadings in the study homes remained approximately 90% below pre-intervention levels. The Baltimore Follow-up Study (MDE, 1995) provides up to 24-month follow-up information on a group of previously abated homes, similar to those included in the R&M study. In these homes, floor dust-lead loadings remained below clearance levels through 14-24 months post-abatement. Dust-lead loadings on window sills and wells remained below pre-abatement levels, but 42% and 47%, respectively, had increased to levels above clearance standards during the same period. Although these homes had been reoccupied post-intervention, blood-lead levels of resident children were not measured.

A New Zealand study (Bates et al., 1995) reported geometric mean blood-lead levels of about 5 μg/dL in resident children of homes that had been abated using chemical stripping, hand or machine sanding, heat gun, water blasting, or blow torch (by professionals) methods. Elevated blood-lead levels (geometric mean of 15.5 μg/dL) were observed in 3 children whose homes were abated by family or friends using blow torch methods. These results are consistent with the discussion of hazardous methods in Appendix B of the previous report (reproduced in Appendix D).

Although the results from all three cities participating in the EPA-sponsored Three-City Urban Soil Lead Abatement Demonstration (3-City) Project are now available, the effectiveness of soil abatement remains unclear. As previously reported, the studied intervention resulted in a 23% decline in blood-lead concentrations in Boston (Weitzman et al., 1993; Aschengrau et al., 1994), with approximately 11.5% due to the soil intervention alone. In Baltimore (USEPA, 1993b), soil abatement did not produce significant declines in blood-lead concentrations, beyond the effect of exterior paint stabilization. In Cincinnati (USEPA, 1993c), the soil abatement group received both soil abatement and interior dust abatement. An initial decline in blood-lead concentrations of the soil abatement group was followed by concentrations that were slightly higher on average than initial levels. Declines of approximately 16.5% were observed in the control groups, which received either no intervention or interior dust abatement. The EPA integrated analysis of these studies (USEPA, 1996e) proposes several factors that may explain the differing results among the three cities. First, the pre-abatement soil-lead concentrations were much higher in Boston (approximately 2,400 ppm) compared to Baltimore (500-700 ppm) and Cincinnati (300-800 ppm), while post-abatement soil-lead concentrations were similar. Thus, the average decrease in Boston (approximately 2,300 ppm) was much greater than that in Baltimore or Cincinnati. In addition, soil was clearly part of the exposure pathway in Boston, contributing significantly to house dust. This was not the case in Cincinnati, where most soil parcels were not adjacent to the housing units. Also, the interior paint stabilization and cleaning interventions conducted along with soil abatement in Boston served to enhance and reinforce the impact of the soil abatement. These treatments were not tested in Baltimore, so that a large reservoir of contaminated house dust remained. These conditions led the authors to conclude that when soil is a significant source of lead in a child's environment, the abatement of that soil will result in a reduction in lead exposure and, hence, a reduction in blood-lead concentration, under certain circumstances. These conditions are not fully understood, but appear to be related to: 1) the child's exposure history, 2) the initial soil-lead concentration and magnitude of reduction, 3) the interior dust-lead loading and magnitude of reduction, 4) the relative magnitude of other exposure sources, and 5) the strength of the exposure pathway between soil and the child, relative to other exposure pathways.

When soil lead is a significant source of lead, soil abatement appears effective in reducing children's blood-lead levels, as seen in three Canadian cities. Extensive, community-wide soil or soil and dust abatements were implemented in each of these cities following the reduction or elimination of an industrial source of lead contamination near a residential area. A 28% decline was observed in Rouyn-Noranda (Gangne, 1994), where emissions were reduced and soil abatements were performed. A 48% decline (17 months post-intervention) was reported in St. Jean-sur-Richelieu (Goulet et al. 1996), where the industrial source was eliminated and both soil and dust abatements were performed. At the post-intervention screening, blood-lead concentrations of children who had lived in the community prior to the intervention were similar to those of a small number of children who had moved to the community after the intervention was completed. The pre- to post-intervention period was longer in the Toronto study (Langlois and Gould, 1996), where emissions were reduced and both soil and dust abatements were performed. A 64% decline in blood-lead concentrations was observed over a 5 year period (1987-1992) in the study area. There is evidence that blood-lead concentrations were declining prior to intervention in the Rouyn-Noranda and Toronto study areas, so that the reported declines may overestimate the effect of the intervention. Two control populations were reported in the Toronto study. Blood-lead concentrations were higher in the study area compared to control areas prior to the intervention. Similar declines were observed in all three areas over a 2 year period, during which interventions took place in the study area. Only one of the control areas was available during the pre- and post-intervention period. Blood-lead levels in the study area declined more slowly than those in the control area prior to the intervention and more rapidly following the intervention.

The remaining studies examined a variety of interim control interventions targeting lead-containing house dust. Four studies utilized professional cleaning. The Minneapolis Dust Intervention Study (Mielke et al., 1994) reported declines in blood-lead concentrations following one-time dust abatement, along with interior paint stabilization and low-cost exterior dust control measures, including covering bare soil. Though average blood-lead concentrations were not reported, the percentage of treatment group children with blood-lead levels greater than 14 µg/dL declined from 39% to 30% during the study period. The percentage of control group children with blood-lead levels greater than 14 µg/dL rose from 41% to 53%, with 24% above 25 µg/dL at the end of the study. None of the treatment group children had a blood-lead concentration above 25 µg/dL at the study end. The New Jersey Children's Lead Exposure and Reduction Study (Rhoads et al., 1999; Lioy et al., 1998) reported a 17% decline in blood-lead concentrations in the treatment group, compared with a 0.9% increase in the control group. In addition, a 34% decline was reported for 16 children whose homes were cleaned more than 20 times during the study, compared to no change for 11 children whose homes were cleaned fewer than 10 times. Dust control through biweekly professional cleaning, combined with multiple education sessions, was effective in this group of children with moderately elevated blood-lead concentrations. A twice-monthly cleaning intervention previously had been reported to be successful in children with higher elevations, in the Baltimore Dust Control Study (Charney et al., 1983). In contrast, the Trail Dust Intervention Study (Hilts et al., 1995) reported no change in blood-lead concentration for either the treatment group, which received professional cleaning every six weeks, or the control group, which received educational materials. A follow-up study (Hilts, 1996) found that biweekly cleaning during the summer months was successful in preventing a seasonal rise in carpet dust-lead loadings and had a moderating effect on the seasonal rise in blood-lead concentrations. An active lead smelter in this community provided a source of continuing recontamination, which makes these studies difficult to compare with the other studies. However, in both the Baltimore (Charney et al., 1983) and Trail (Hilts et al., 1995) studies, dust-lead levels declined during the study, but rose again within a few weeks after cleaning was discontinued. Finally, the Boston Interim Study (Aschengrau et al., 1998; Mackey et al., 1996) provides evidence that one-time cleaning prior to abatement may be effective in reducing lead exposure of children until abatement can be performed. A 48% decline in blood-lead concentration was observed among 8 children who were exposed to "severe" household lead hazards and were assigned the intervention, compared to 35-36% declines in the randomized intervention and control groups, who faced less severe hazards. Window sill dust-lead loadings decreased in the control group, suggesting that residents may have done some cleaning. The statistical power of this study was low due to the small number of children who completed the study.

4.2 EDUCATIONAL INTERVENTIONS

As reported in the original edition, intensive, in-home educational interventions appeared to be successful in reducing blood-lead concentrations in the Milwaukee (USEPA, 1996c; Schultz et al., 1998) and Granite City (Kimbrough et al., 1994) studies. A variety of educational interventions have now been assessed in Leadville, (LCBH and UC, 1993), Rochester (Lanphear et al., 1996), Trail (Hilts et al., 1995), and East St. Louis (Copley, 1995), with mixed results. A 19% decline was reported for a small number of children in Leadville, which is similar to previously reported results in Milwaukee (19%) and Granite City (34%). Low-cost educational interventions primarily consisting of distribution of educational materials were conducted in

Rochester and Trail (control group). Small or no declines in blood-lead concentrations resulted from these interventions. In Rochester, the reported decline in the control group, which received only a brochure, was larger than that reported for the treatment group, which received cleaning supplies and instruction, although the reported results were not significantly different (from each other nor from 0). This was a well-conducted study using randomized treatment and control groups. It may be, however, that the sample size was insufficient to detect a small difference between the studied treatment and control interventions.

Finally, the effectiveness of educational intervention relies on the willingness of the family to follow through with the recommendations given. There is evidence that cleaning by residents can reduce household dust-lead levels and children's blood-lead levels. The East St Louis study reported 50% declines in dust-lead loadings in the 44% of homes where the family reported that they had cleaned according to instruction. No follow-up blood-lead measurements were collected. In addition, a 36% decline in blood-lead concentrations and a 38% decline in window sill dust-lead loadings were observed in control homes for the Boston Interim study (Mackey et al., 1996), where the control population received an outreach visit, cleaning instructions, and a free sample of cleaning solution. Minor increases in floor and window well dust-lead loadings were observed. Floor dust-lead levels were initially low, so that the increase was inconsequential. Window well loadings, however, were initially high and remained so. Although blood-lead concentrations did not decrease in the Rochester Study, 30 - 60% declines in dust-lead loadings were reported for most surfaces (except window wells) following cleaning.

5.0 CONCLUSIONS & RECOMMENDATIONS

Any effort to derive conclusions and recommendations from the lead hazard intervention effectiveness data summarized in Section 4.0 must recognize its scope as well as its limitations. Since publication of the earlier review, a surprising number and variety of intervention strategies have been documented in the scientific literature. These studies have helped to fill some of the research "gaps" noted in the earlier review. However, these same studies have also reemphasized certain areas of remaining investigation and prompted new questions. The need for research surrounding the effectiveness of the lead hazard intervention strategies remains.

Despite the remaining issues, there are some important conclusions that may be drawn from the existing body of research. Section 5.1 documents the general conclusions regarding the effectiveness of lead hazard intervention. Section 5.2, in turn, reviews those conclusions relevant to specific intervention strategies targeting paint, dust, and soil. There are also on-going studies that, when complete, may further supplement the conclusions. Section 5.3 discusses those studies, known to the authors of this report, that were not complete (or publishable) at this time. Finally, besides conclusions, the existing evidence suggests areas where research is still required (i.e., data "gaps"). The remaining data "gaps" and recommendations for future research are made in Section 5.4.

5.1 CONCLUSIONS REGARDING EFFICACY OF LEAD HAZARD INTERVENTION

Though there is substantial and varied evidence within the literature that lead hazard intervention can reduce exposed children's blood-lead concentrations, no single intervention strategy stands out as markedly superior. A range of intervention strategies were shown to reduce children's blood-lead concentrations. However, not all intervention strategies studied were effective. Short-term elevations in exposed children's blood-lead concentrations did result when abatements were performed improperly by current standards (e.g., Baltimore Traditional vs. Modified). Other intervention strategies reported no efficacy in the targeted population (e.g., Rochester Educational) or no greater effectiveness than their associated control populations (e.g., Baltimore 3-City).

It was the case, however, that declines on the order of 25% were reported among children benefitting from extensive, carefully managed projects which abated or isolated sources of lead, as well as among children receiving regular cleaning procedures or extensive educational instructions employed to alleviate their lead exposure (Figure 5-1a and 5-1b). Moreover, a range of lead hazard intervention strategies was documented to have a statistically significant positive “effect” on the blood-lead concentrations of exposed children, compared to control populations that did not receive the intervention. In particular, lead-based paint abatement (e.g., 1990 St. Louis Retrospective), dust-lead intervention (Baltimore Dust Control), soil-lead intervention (Boston 3-City), and educational intervention (Milwaukee Retrospective) were documented to have at least the *potential* for producing significantly greater declines in blood-lead concentration among children benefitting from the intervention than among a control population of children. The comparable efficacy is potential in that not all examples of each of these strategies were effective. Paint abatement was not effective in the Boston 3-City study, soil abatement was not effective in Baltimore and Cincinnati 3-City studies, dust control was not effective in the Trail study, and education was not effective in the Rochester study. The specific details of the effective intervention strategies were critical. For example, paint intervention strategies that were effective in children with blood-lead concentrations above 20 µg/dL were not necessarily effective in children with lesser elevations (Baltimore R&M, Central Massachusetts Retrospective).

It should also be noted that the comparability in effectiveness of a range of intervention strategies does not imply they are interchangeable. Instead, it suggests that other relevant factors serve as the determinants of what strategy is suitable for a given situation. These factors include the strategy’s cost (both up-front and long-term), its viability, the type of lead exposure facing the child, and the expected long-term efficacy. Educational and interim control interventions are generally regarded as requiring lower up-front expenses, but require continued performance at regular intervals which may well result in higher long-term cost. Regular dust control was effective in Baltimore, but ineffective in Trail where rapid recontamination may have almost immediately overwhelmed the successful (in terms of dust-lead levels) cleaning efforts. Educational strategies can fail to retain their initial effectiveness as participants fail to continue their cleanup efforts (East St. Louis). The appropriateness of a particular intervention strategy must be considered beforehand in the specific context under which it is to be implemented if the

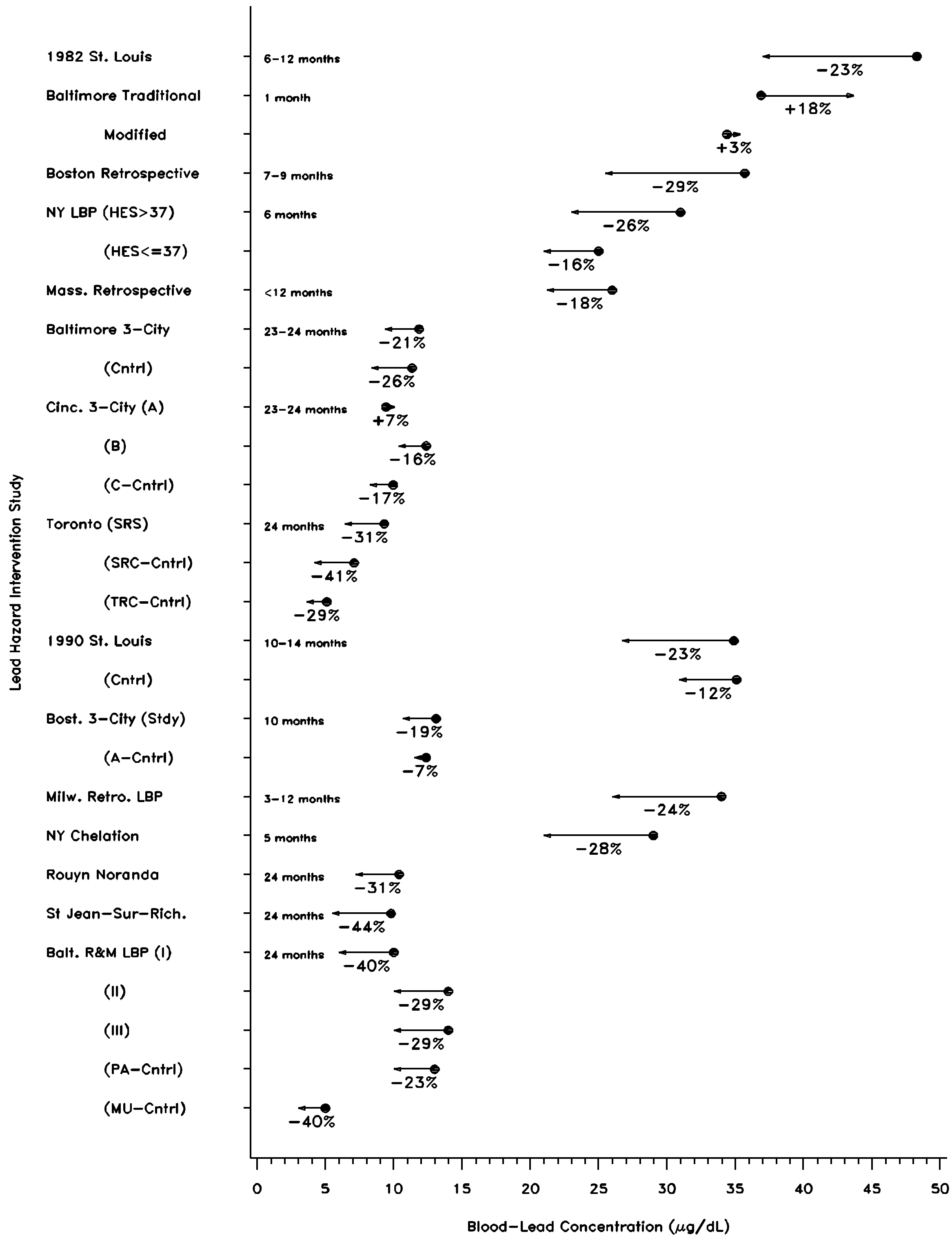


Figure 5-1a. Summary of Blood-Lead Concentration Results for Identified Lead Hazard Abatement Studies and Interim Control Studies Targeting Lead-Based Paint.

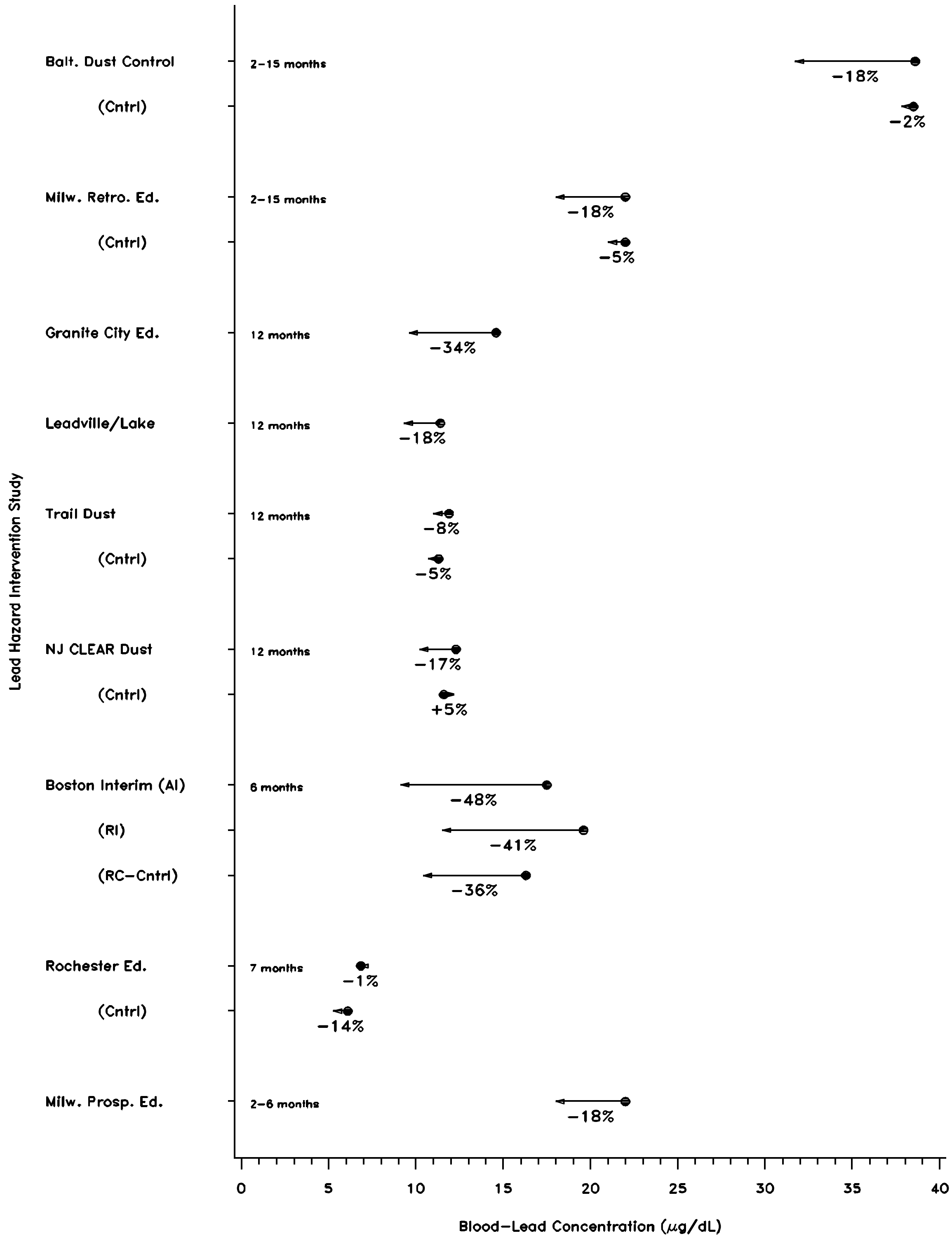


Figure 5-1b. Summary of Blood-Lead Concentration Results for Identified Cleaning and Education Studies.

strategy is to have a reasonable chance of reproducing the effectiveness documented in the literature.

The seemingly inconsistent effectiveness reported for a particular type of intervention (e.g., education) may be explained, at least in part, by the wide variation in the specific details of the intervention (e.g., a home visit by a physician versus a pamphlet left with the family). However, the potential confounding impact of the child's initial blood-lead concentration should also be recognized. As evidenced in Figures 3-5 and 3-8 above (and Figure 3-19 in the earlier review, reproduced in Appendix C), greater declines in blood-lead concentrations are observed among children with higher pre-intervention blood-lead concentrations. Also, the Baltimore R&M, Central Massachusetts Retrospective, and 1990 St. Louis Retrospective studies all noted that statistically significant declines in blood-lead concentration were observed for children with initial blood-lead concentrations in excess of 20 µg/dL, while no mean decline was reported for children with initial blood-lead levels less than 20 µg/dL. In fact, the Massachusetts Retrospective study noted that the mean post-intervention blood-lead concentration among children with initial blood-lead levels less than 20 µg/dL increased by 15%. The basis for this trend is uncertain, though perhaps it stems from differences in the lead exposure mechanisms for the two populations. Children with blood-lead concentrations in excess of 20 µg/dL may derive their exposure primarily from a single residential source, which may be successfully targeted by an intervention. Children with lower blood-lead concentrations, by contrast, may be exposed to a wide range of sources. A blood-lead concentration below 20 µg/dL does not require a single significant exposure source; incremental exposures to several lesser sources may well be sufficient. Regardless, caution should accompany any effort to extend results observed among children with elevated blood-lead concentrations to those with lower levels.

5.2 CONCLUSIONS REGARDING SPECIFIC INTERVENTION STRATEGIES

Given the number of intervention efficacy studies reported, it is worthwhile to review the conclusions that may be derived regarding the range of intervention strategies commonly cited as relevant to regulatory efforts such as §403. The efficacy of particular methods is not always clear, as many studies assessed a combined intervention strategy. To the extent possible, the scientific evidence on efficacy of specific intervention techniques targeting lead-based paint, lead in dust, and lead in soil is summarized below.

5.2.1 Lead-Based Paint Intervention

Strategies targeting lead-based paint sought to either permanently abate the lead hazard, or prevent continued exposure for extended periods of time.

Hand-Scraping Removal with a Heat Gun. This procedure entails using a heat gun to soften the paint, then using a hand-scraping tool to remove it. A respirator is required during this procedure due to the reported potential release of volatile fumes (NIOSH, 1992). The procedure had mixed success in abating paint from floors and window sills (HUD, 1991), and was associated with slight (though not statistically significant) elevations in the blood-lead levels of resident children within one month of abatement (Farfel and Chisolm, 1990). This method was not associated with elevated blood-lead concentrations two years post-intervention (Bates et al., 1997).

Mechanical Removal. Methods that mechanically remove the leaded paint include needle guns, vacuum blasting, and abrasive (wet and dry) sanding. Devices for performing these procedures are sometimes fitted with a high-efficiency particulate accumulator (HEPA) dust collection system, since these methods can generate a great deal of dust (HUD, 1991). In some instances, the surface is misted to contain dust and avoid aggravating the lead hazard (Amitai et al., 1991). There is little data available on the effectiveness of these procedures. This method was not associated with elevated blood-lead concentrations two years post-intervention (Bates et al., 1997).

Chemical Removal. This procedure entails the application of a caustic chemical to the painted surface, allowing the chemical to work its way into the paint, and then removing the paint from the component. Worker protection is necessary against the caustic and flammable chemicals. The procedure can produce a large amount of hazardous waste. The procedure may be useful when historical preservation is necessary. Mixed success was exhibited in abating floors, window sills, and window wells using chemical removal (HUD, 1991). This method was not associated with elevated blood-lead concentrations two years post-intervention (Bates et al., 1997). This method was successful when used in combination with encapsulation and component replacement strategies (Nedellec et al., 1995).

Component Replacement. This strategy of abatement entails removing the component in question (e.g., doors, windows, trim) and replacing it with a new component, or thoroughly stripping the leaded paint at an off-site location and reinstalling the original component. Removal and replacement has been a successful abatement strategy (HUD, 1991; Farfel, 1991), and produced declines in resident children's blood-lead levels within one month of abatement (Amitai et al., 1991). Window replacement may be the most common application of this strategy (USEPA, 1995b, 1997, 1998a; NCLSH and UC, 1997). Preliminary results of the HUD Abatement Grant Program suggest that this strategy can be effective in reducing dust-lead levels in the home and blood-lead levels of resident children (NCLSH and UC, 1998).

Enclosure. Enclosure as an abatement practice involves resurfacing or covering the painted surface with a rigid, solid material (e.g., drywall, gypsum board, or plywood) and caulking with durable materials at the corners and edges to prevent escape of leaded dust or paint chips. The enclosing material is fastened mechanically to the base substrate or underlying structural component. Warning signs are placed underneath the enclosure materials in case of future disturbances. Given the potential for penetrating the enclosure barrier, only durable enclosure materials should be used on surfaces regularly subjected to abrasion (e.g., window wells). Enclosure has been successfully implemented as an abatement strategy (HUD, 1991; NCLSH and UC, 1997, 1998) and was effective in lowering the blood-lead concentrations of resident children one month following the intervention (Amitai et al., 1991). Dust-lead levels in residences predominantly abated using encapsulation or enclosure methods were typically, though not significantly, higher than those measured in residences primarily abated using removal methods (USEPA, 1996a, 1996b). Preliminary results of the HUD Abatement Grant Program suggest that this strategy can be effective in reducing dust-lead levels in the home and blood-lead levels of resident children (NCLSH and UC, 1998).

Encapsulation. This method involves coating surfaces with durable coatings to prevent the underlying lead from becoming part of house dust or accessible to children. The coatings are specifically formulated to be elastic, long-lasting, and resilient to cracking, peeling, algae and fungus. Rigid materials that are adhesively bonded (as opposed to mechanically fastened) to the leaded paint surface are also considered encapsulants. It is not expected that encapsulants will last as long as mechanically fastened enclosures. As with enclosure, encapsulation is not suitable for friction surfaces. The limited data on the efficacy of encapsulation methods indicates dust-lead levels in residences abated predominantly using encapsulation or enclosure methods were typically, though not significantly, higher than those measured in residences abated primarily using removal methods (USEPA, 1996a, 1996b). Encapsulation was successful when used in combination with chemical stripping and component removal strategies (Nedellec et al., 1995). Preliminary results of the HUD Abatement Grant Program suggest that encapsulation can be effective in reducing dust-lead levels in the home and blood-lead levels of resident children (NCLSH and UC, 1998).

Interim Controls. This strategy seeks to manage the lead-based paint hazard rather than abate it. Peeling or chalking leaded paint is removed (e.g., wet scraping and sanding) and the surface repainted. Intact leaded paint is not disturbed. Specialized cleaning is also required. Whenever further leaded paint deterioration occurs, the same maintenance procedures are utilized. Interim control strategies have resulted in significant declines in residential dust-lead loadings and concentrations, as well as modest declines in the blood-lead levels of resident children 9-15 months after the interventions (Weitzman et al., 1993; USEPA, 1993b, 1995b, 1997, 1998a). Preliminary results of the HUD Abatement Grant Program suggest that interim controls can be effective in reducing dust-lead levels in the home and blood-lead levels of resident children (NCLSH and UC, 1998).

5.2.2 Lead-Containing Dust Intervention

Dust may exhibit elevated lead levels due to migration from lead sources such as soil lead or deteriorating leaded paint. Therefore, any intervention targeting elevated levels of dust lead must be performed regularly, since the source of the lead is not abated by the intervention.

Removal. This strategy removes the lead-containing dust by thoroughly wet mopping the residence, usually with a detergent solution. Alternatively, HEPA vacuuming, or a combination of the two methods, may be employed. Surfaces of the residence (e.g., floors, table tops, counters, window sills) exhibiting elevated levels of dust lead are wet wiped or mopped. This process must be repeated regularly since residential dust can rapidly become recontaminated. Charney, et al. (1983), noted that dust-lead concentrations had returned to original levels two weeks following a thorough residential cleaning. If performed regularly, however, dust removal intervention can significantly reduce residential dust-lead loadings (Charney et al., 1983). More importantly, it can moderately reduce (18%) the blood-lead concentrations of exposed children by one year following its initiation (Charney et al., 1983; Rhoads et al., 1999). The study reported by Rhoads, et al., also found that conscientious, regular cleaning could result in a 50% decline in dust-lead levels. Hilts et al. (1995) reported no change in blood-lead concentrations resulted from a less frequent cleaning schedule (every six weeks). However, an active lead smelter provided a source of continuing recontamination in this community that was not present in other study communities. One-time cleaning was successful in reducing blood-lead levels of children whose homes were scheduled to be abated (Mackey et al., 1996).

Education. The effect of a dust lead hazard may be reduced by educating both the children and their parents about the potential for exposure. This education may be quite varied in both its character and the manner in which it is provided. Parents may be provided materials about the danger from hand-to-mouth behavior and the benefits of washing the child’s hands regularly. Alternatively, a cleaning kit may be provided to the family, accompanied by training on how best to reduce residential dust-lead levels. In all instances, the goal is to halt the pathway of lead from the residential dust to the child's blood. Educational interventions rely on the initiative of the family to implement the recommended procedures. Educational interventions have been effective in reducing residential dust-lead hazards (Roberts et al., 1991; Copley, 1996; Lanphear et al., 1996), as well as children's blood-lead concentrations (Kimbrough et al., 1994; USEPA, 1996c; LCDH and UC, 1993; Mackey et al., 1996). Small or no declines in blood-lead concentrations have also been reported following educational interventions (Lanphear et al., 1995, 1996; Hilts et al., 1995). However, note that the Lanphear et al., 1996 study investigated a very limited educational intervention for children at quite low blood-lead levels and probably had limited power for detecting any blood-lead effect, even if it existed. The Hilts et al., 1995 intervention in Trail, British Columbia, Canada, had an active lead smelter, which provided a source of continuing recontamination that was not present in other study communities.

5.2.3 Lead-Containing Soil Intervention

Like leaded paint intervention, strategies targeting elevated soil-lead concentrations seek to abate or manage a source of lead exposure. The lead reservoir in soil may be the result of years of leaded gasoline emissions, peeling exterior leaded paint, and in some areas, mining or smelting operations.

Removal and Replacement. Under this intervention strategy, the soil exhibiting elevated levels of lead is removed and replaced with soil of minimal (or background) lead concentration. The contaminated soil is removed to a depth sufficient to either abate all the contamination or to preclude contaminated soil from being readily uncovered. In addition, grass may be sown to prevent erosion. Weitzman et al. (1993) document the implementation of a soil removal and replacement strategy in Boston, MA, and the resulting moderate reduction (23%) in the blood-lead concentrations of resident children 11 months following the abatement. Similar soil removal and replacement strategies were less effective in other locations, where initial conditions were less severe (USEPA, 1993b, 1993c). In these communities, control group children exhibited declines in blood-lead concentration as large, or larger, than children receiving soil abatement Community-wide soil abatement projects following the reduction or elimination of industrial lead sources have resulted in reduced blood-lead concentrations in resident children (Langlois and Gould, 1996; Gangne, 1994; Goulet et al., 1996).

Enclosure. This strategy encloses the contaminated soil to prevent access to or mobilization of the lead. The enclosure consists of long-term soil coverings such as asphalt or concrete. Though such a procedure was employed for a small number of homes in the Baltimore portion of the Three-City Soil Abatement Demonstration Study (USEPA, 1993b), the efficacy of these interventions was not reported separately from removal and replacement interventions performed for the remaining study homes. In addition, no results are currently available on the degree to which such enclosures degrade over the long-term (e.g., 20 years).

Interim Controls. This strategy maintains a cover over the contaminated soil to prevent access to or mobilization of the lead. Potential soil coverings include grass sod and gravel. If grass is used it may be appropriate to provide a sprinkler system to help ensure the continued survival of the grass. Such coverings depend upon continued effort to maintain the effectiveness of the covering. An intervention that included both soil cover and interior dust abatement was effective in reducing blood-lead concentrations in the study group five months after the intervention as compared to a control group that received preventive information (Mielke et al., 1994). Additional studies have implemented soil cover interventions (Hilts, 1996; Calder et al., 1994), but the effectiveness of the soil cover intervention separately from other components of the overall intervention strategy. No other studies that document the effectiveness of this intervention strategy were identified in the scientific literature.

Education. A soil lead hazard may also be restricted by educating both the children and their parents about the danger. Parents may be provided materials about the danger from hand-to-mouth behavior or encouraged to take the child to safe playgrounds in the area. The goal is to halt the pathway of lead from the residential soil to the child's blood. Such educational efforts may be conducted in combination with education on the danger of residential lead-containing dust. Since the lead-containing soil has not been abated, the potential for contamination of the interior house dust remains. No literature was identified on the effectiveness of this strategy.

5.3 ONGOING RESEARCH

The studies summarized in this report help to provide a more complete picture of the effectiveness of lead hazard intervention than that presented in the prior summary. However, the data are still limited. Additional studies are under way that focus on primary prevention, the longer term effectiveness of lead hazard intervention, effectiveness of interventions for children with moderately elevated blood-lead levels (i.e., 10-20 µg/dL), and the effectiveness of additional low-cost (at least up-front) intervention methods. It is anticipated that these studies will help complete and sharpen the remaining issues relevant to lead hazard intervention.

PRIMARY PREVENTION

The Baltimore R&M project has enrolled babies born into study homes. These babies will be followed in order to assess primary prevention effectiveness. Other studies that have been funded by government agencies include a matched cross-sectional study that utilizes blood-lead screening and abatement information collected by the Massachusetts Department of Health (funded by EPA and CDC) and a primary prevention project in Providence, RI and Chicago, IL (funded by CDC and HUD).

LONGER TERM EFFECTIVENESS

Preliminary Results from the New Jersey Children’s Lead Exposure and Reduction (CLEAR) dust intervention study (Rhoads et al., 1999) were summarized in this report. This ongoing study will follow children for two years. The Baltimore R&M study (USEPA, 1995b, 1997, 1998a) will continue follow-up beyond two years, with additional funding from HUD. The HUD Abatement Grant Program is a large scale, ongoing study that will provide 2-3 year follow-up of interventions conducted in 9 sites. Additional ongoing studies in Cleveland and Massachusetts (state), jointly funded by EPA and CDC, will measure blood and dust lead for up to two years following a variety of interventions.

MODERATELY ELEVATED BLOOD-LEAD CONCENTRATIONS

A prospective study, which includes a control population, will assess the efficacy of educational outreach visits conducted by the Milwaukee Health Department in reducing blood-lead concentrations, or preventing further increases, of children under two years of age whose initial blood-lead concentration is between 15 and 19 µg/dL. The effectiveness of these outreach visits has been demonstrated for children with blood-lead concentrations above 20 µg/dL (Schultz et al., 1998; USEPA, 1996c).

A randomized trial of dust control involving 275 children followed from 6 months of age until they attained 24 months of age was conducted by Lanphear and colleagues at the University of Rochester School of Medicine, Rochester, NY. Of the 275 children, 140 (51%) were randomly assigned to receive up to 8 visits by a trained dust control advisor, cleaning equipment and supplies. The remaining 135 children were assigned to a control group. Outcome measures include geometric mean blood-lead levels and the percent of children having a blood-lead level in excess of 10 µg/dL, 15 µg/dL, and 20 µg/dL by group assignment (Lanphear et al., 1998).

LOW-COST INTERVENTIONS

The HUD Abatement Grant Program is encouraging state and local governments to experiment with new and innovative low-cost intervention strategies (NCLSH and UC, 1997). One grantee plans to evaluate the effectiveness of the intervention in improving neurobehavioral functioning in Kansas City children. In addition, a study of low-cost abatement methods is being conducted in Baltimore.

5.4 RECOMMENDATIONS FOR FUTURE RESEARCH

While each research study has unique objectives, a goal in conducting research is always to add to the body of knowledge in the subject area. Thus, comparisons are made between the results of a new research study and those that preceded it. These comparisons may be made in a review article or report, such as this one, or by another researcher in the course of planning a study. Although the specific study objectives must always determine the primary outcome measurements, we make recommendations in this section that could facilitate the comparison of new study results to other research. In addition, we identify areas where additional research is needed to provide a more complete understanding of lead hazard intervention effectiveness.

In order to compare results across studies, consistent outcome measurements must be available. We have found that not only must the same endpoints (e.g., blood-lead concentration) be measured, but that the timing relative to intervention and sampling method should be similar. For example, comparison of venous and capillary blood-lead measurements can be problematic. We note that some of the more common endpoints measured in the abatement literature were blood-lead concentration and dust-lead loadings on floors, window sills, and window wells. Blood-lead concentration was most commonly measured by venous blood draws and we recommend continued use of that method whenever possible. Dust-lead loadings were measured using a variety of vacuum or wipe sampling methods. Although there are advantages to both types of methods, wipe sampling is relatively inexpensive and attractive to many researchers for that reason. Thus we recommend that, when environmental measures are included in a study, at least some wipe samples be collected. Finally, the timing of measurements relative to the intervention is very important. Pre-intervention measures should be collected to provide a basis for comparison even within the study. The timing of post-intervention measures depends, however, on the specific objectives of the study. Some time points, however, appear to be globally important. For environmental measures, clearance samples are needed to verify that the studied intervention did remove the targeted lead hazard. These samples also provide a baseline for the assessment of recontamination of environmental media. Follow-up sampling at one year post-intervention is recommended for both blood and dust measurements, to minimize the effect of seasonal variability, at least for blood-lead measurements. In addition, random assignment of homes into intervention and control groups is highly recommended wherever possible, the power of the study to detect differences of interest should be considered, and, of course, other good research practices implemented.

The body of research examining the effectiveness of lead hazard interventions still contains substantial "gaps" that need to be addressed before a complete understanding of the issue is possible. Certainly, there are intervention strategies that are employed today but not yet documented in the scientific literature (e.g., covering soil exhibiting elevated lead concentrations). While such documentation would greatly facilitate EPA in its regulatory efforts, it is likely there will always be some new strategy being considered that has not had its efficacy scientifically documented. The rapid pace of technology and the continuing dissemination of information regarding the benefits and/or dangers of studied interventions (e.g., via this report) will ensure new strategies are constantly being developed. There are, however, other data gaps that are more pressing given their fundamental implications to understanding lead hazard intervention.

There is little if any documentation regarding the long-term effectiveness of intervention. Some studies have examined efficacy for 2-3 years post-intervention and others are planned, or are in progress. In addition, the Baltimore R&M study included a group of previously abated homes, providing 4-6 year follow-up of those abatements. However, that is only one study and even that length of time may be insufficient. Do interventions retain their efficacy for five years? Ten years? There are factors which challenge long-term efficacy. There is often the potential for recontamination from neighboring residences not necessarily benefitting from any intervention. So too may the intervention strategy itself gradually lose its effectiveness. Dust cleaning practices prompted by educational outreach may gradually be abandoned over time. Lead hazard encapsulations may age, thereby losing some of their ability to shield the still present lead source. Long-term efficacy is also a question based on the uncertainties of human lead exposure. Bone-lead stores have the potential to partially mask the effectiveness of an intervention for extended periods of time (Rust et al., 1999; USEPA, 1998b). Given sufficient time, do blood-lead concentrations eventually decline to levels consistent with the post-intervention environment? Until long-term efficacy is considered, it is difficult to fully anticipate the long-term consequences of interventions.

It has already been noted that no data exist regarding primary prevention effectiveness rather than secondary (Section 2.2). Too often an exposed child represents the first indication of a lead hazard. EPA is working to rectify that with the promulgation of the §403 rule defining lead hazards in paint, dust, and soil. It is hoped these definitions will permit identification of residences requiring intervention before a child is exposed. What degree of effectiveness might be expected from such interventions? This same question is relevant even without the §403 rule in that new families routinely move into residences whose lead hazards have already been intervened. Given the role of retained lead in body stores, it is reasonable to expect primary prevention efficacy to exceed secondary prevention efficacy. The extent to which it does, however, is critical.

6.0 REFERENCES

Agency for Toxic Substances and Disease Registry (1988) “The Nature and Extent of Lead Poisoning in Children in the United States: A Report to Congress.” Atlanta: U.S. Department of Health and Human Services, Public Health Service. DHHS Document No. 99-2966.

Amitai, Y., Graef, J.W., Brown, M.J., Gerstle, R.S., Kahn, N., and Cochrane, P.E., (1987) ?Hazards of ‘Deleading’ Homes of Children with Lead Poisoning.” *American Journal on Diseases of Children*. 141:758-760.

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

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.

Aschengrau, A., Beiser, A., Bellinger, D., Copenhafer, D., Weitzman, M., (1997) “Residential Lead-Based-Paint Hazard Remediation and Soil Lead Abatement: Their Impact among Children with Mildly Elevated Blood Lead Levels.” *American Journal of Public Health*. 87(10):1698-1702.

Aschengrau, A., Hardy, S., Mackey, P., and Pultinas, D. (1998) “The Impact of Low Technology Lead Hazard Reduction Activities among Children with Mildly Elevated Blood Lead Levels.” *Environmental Research*. 79:41-50.

ATSDR (1993) “Toxicological Profile for Lead.” Final Report of the Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. Department of Health and Human Services. April 1993.

Barry, P.S.I., and Mossman, D.B., (1970) “Lead Concentration in Human Tissues.” *British Journal of Industrial Medicine*. 27:339-351.

Barry, P.S.I., (1975) “A Comparison of Concentrations of Lead in Human Tissues. *British Journal of Industrial Medicine*. 32:119-139.

Barry, P.S.I., (1981) “Concentrations of Lead in the Tissues of Children,” *British Journal of Industrial Medicine*. 38:61-71.

Batschelet, E., Brand, L., Steiner, A., (1979) “On the Kinetics of Lead in the Human Body.” *J. Math Biology*. 8:15-23.

Battelle Memorial Institute (1994a) “Reported Effectiveness Derived from Methods for Lead Hazard Intervention.” Memorandum to U.S. EPA, Office of Pollution Prevention and Toxics, prepared under Contract No. 68-D2-0139. September 1994.

Bellinger, D., Leviton, A., Waternaux, C., Needleman, H., and Rabinowitz, M., (1987) "Longitudinal Analysis of Prenatal and Postnatal Lead Exposure and Early Cognitive Development." *New England Journal of Medicine*. 316:1037-1043.

Bert, J.L., van Dusen, L.J., and Grace, J.R., (1989) "A Generalized Model for the Prediction of Lead Body Burdens. *Environmental Research*. 48: 117-127.

Buckley, T.J., (1996) "Selection Criteria for CLEARS Relating to Blood-Pb." Personal Communication to Brad Schultz. March 22, 1996.

Buckley, T.J., (1996) "Significant Findings from the *Children's Lead Exposure and Reduction Study* (CLEARS)." U.S. EPA Memorandum. May 2, 1996.

Burgoon, D.A., Rust, S.W., and Schultz, B.D., (1993) "A Summary of Studies Addressing the Efficacy of Lead Abatement." Draft proceedings for ASTM Lead in Paint, Soil, and Dust Conference. 1993.

Burgoon, D.A., Rust, S.W., and Schultz, B.D., (1995) "A Summary of Studies Addressing the Efficacy of Lead Abatement," Lead in Paint, Soil, and Dust. Health Risks, Exposure Studies, Control Measures, Measurement Methods, and Quality Assurance, ASTM STP 1226, Michael E. Beard and S.D. Allen Iske, Eds., American Society for Testing and Materials, Philadelphia.

Calder, I.C., Maynard, E.J., Heyworth, J.S., (1994) "Port Pirie Lead Abatement Program, 1992." *Environmental Geochemistry and Health*. 16(3/4):137-145.

Centers for Disease Control (1991) "Preventing Lead Poisoning in Young Children - A Statement by the Centers for Disease Control." Atlanta: U.S. Department of Health and Human Services. October 1991.

Centers for Disease Control (1997) "Screening Young Children for Lead Poisoning: Guidance for State and Local Public Health Officials." Atlanta: U.S. Department of Health and Human Services. November 1997.

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.

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

Chisolm, J.J. Jr., Mellits, E.D., and Quaskey, S.A. (1985) "The Relationship between the Level of Lead Absorption in Children and the Age, Type, and Condition of Housing." *Environmental Research.* 38:31-45.

Christoffersson, J.O., Ahlgren, L., Schutz, A., Skerfving, S., and Mattsson, S., (1986) “Decrease of Skeletal Lead Levels in Man after End of Occupational Exposure.” *Archives of Environmental Health*. 41:5: 312-318.

Cohen, N., Jaakkola, T., Wrenn, M.E., (1973) “Lead-210 Concentrations in the Bone, Blood, and Excreta of a Former Uranium Miner.” *Health Physics*. 24: 601-609.

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.

Copley, C., (1995) “East St. Louis Lead Dust Reduction in Homes of At-Risk Children.” Report on Grant NE995974-01 to U.S. Environmental Protection Agency. October 1995.

Copley, K., (1996) Personal Communication. June 1996.

Cristy, M., Leggett, R.W., Dunning, D.E., Jr., and Eckerman, K.F., (1986) “Relative Age-specific Radiation Dose Commitment Factors for Major Radionuclides Released from Nuclear Fuel Facilities.” NUREG/CR-4628 ORNL/TM-9890.

Ewers, L., Clark, S., Menrath, W., Succop, P., Bornschein, R., (1994) “Clean-up of Lead in Household Carpet and Floor Dust.” *Am. Hyg. Assoc. J*. 55:650-657.

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

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*. 66:199-212.

Farfel, M.R., Rohde, C., Lees, P.S.J., Rooney, B., Bannon, D.I., Alvi, L., (1995) “Preliminary 12-Month Report of the Lead Paint Abatement and Repair and Maintenance Study in Baltimore”, Kennedy Krieger Research Institute Report for EPA.

Feldman, R.G. (1978) “Urban Lead Mining: Lead Intoxication Among Deleaders.” *New England Journal of Medicine*. 298:1143-1145.

Fischbein, A., Anderson, D.E., Sassa, S., Lilis, R., Kon, S., Sarkozi, L., and Kappas, A. (1981) “Lead Poisoning from ‘Do-It-Yourself’ Heat Guns for Removing Lead-Based Paint: Report of Two Cases.” *Environmental Research*. 24:425-431.

Freeman, N.C.G., Wainman, T., Lioy, P.J., (1996) "Field Testing of the LWW Sampler and Association of Observed Household Factors with Dust Loading." *Applied Occupational and Environmental Hygiene*. 11:476-483.

Gangne, D., (1994) "Blood Lead Levels after Removal of Contaminated Soil". *Canadian Journal of Public Health*. 85:3, May-June 1994.

Goulet, L., Gaudreau, J., and Messier, A., (1996) "Results of a Lead Decontamination Program", *Archives of Environmental Health*. 51(1):68-72.

Goyer, R.A., (1993) "Lead Toxicity: Current Concerns." *Environmental Health Perspectives*. 100:177-187.

Gulson, B.L., Mahaffey, K.R., Mizon, K.J., Korsch, M.J., Cameron, M.A., and Vimpani, G.(1995) "Contribution of Tissue Lead to Blood Lead in Adult Female Subjects Based on Stable Lead Isotope Methods." *Journal of Lab and Clinical Medicine*. 125: 703.

Heard, M.J., and Chamberlain, A.C., (1984) "Uptake of Pb by Human Skeleton and Comparative Metabolism of Pb and Alkaline Earth Elements." *Health Physics*. 47: 857-865.

Hernberg, S., Nikkanen, J., Mellin, G., et al., (1970) "δ-Aminolevulinic Acid Dehydrase as a Measure of Lead Exposure." *Archives of Environmental Health*. 21:140145.

Hilts, S.R., Hertzman, C., Marion, S.A., "A Controlled Trial of the Effect of HEPA Vacuuming on Childhood Lead Exposure." *Canadian Journal of Public Health*. 86(5):345-350. September-October 1995.

Hilts, S.R.(1996) "A Co-operative Approach to Risk Management in an Active Lead/Zinc Smelter Community." *Environmental Geochemistry and Health*. 18(1):17-24.

Hilts, S.R., Bock, S.E., Oke, T.L., Yates, C.L., Copes, R.A. (1998) "Effect of Interventions on Children's Blood Lead Levels." *Environmental Health Perspectives*. 106(2):79-83. February.

Hyrhorczuk, D., Rabinowitz, M., Hessel, S., Hoffman, D., Hogan, M., Mallin, K., Finch, H., Orris, P., and Berman, E., (1985) "Elimination Kinetics of Blood Lead in Workers with Chronic Lead Intoxication." *American Journal of Industrial Medicine*. 8:33-42.

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.

Janin, Y., Couinaud, C., Stone, A., et al., (1985) "The 'Lead-Induced Colic' Syndrome in Lead Intoxication." *Surg. Ann.* 17:287-307.

Kimbrough, R.D., (1992) Statement to the Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, U.S. House of Representatives. June 9, 1992.

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

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

Lake County Department of Health and University of Cincinnati, “The Leadville/Lake County Environmental Health Lead Study — Report of the 1992 Follow-up Lead Screening.” July 12, 1993.

Langlois, P., And Gould R., (1996) “Blood Lead Levels in Toronto Children and Abatement of Lead-Contaminated Soil and House Dust.” *Archives of Environmental Health*. 51(1):59-67.

Lanphear, B.P., Winter, N.L., Apetz, L.J., Eberly, S., Weitzman, M., (1995) “A Randomized Trial of the Effect of Dust Control on Children’s Blood Lead Levels.” Report on Grant NYLPR002-94 Submitted to U.S. Department of Housing and Urban Development, Washington, D.C. and National Center for Lead-Safe Housing, Columbia, MD.

Lanphear, B.P., Winter, N.L., Weitzman, M., (1996) “A Randomized Trial of the Effect of Dust Control on Children’s Blood Lead Levels.” *Pediatrics*. 98(1):35.

Lanphear, B.P., (1998) Personal Communication and conference presentation. July 1998.

Leggett, R.W., Eckerman, K.F., and Williams, L.R., (1982) “Strontium-90 in Bone: A Case Study in Age-Dependent Dosimetric Modeling.” *Health Physics*. 43(3):307-322.

Lioy, P.J., Yiin, L., Adgate, J.,Weisel, C.P., Rhoads, G.G., (1998), “The Effectiveness of a Home Cleaning Intervention Strategy in Reducing Potential Dust and Lead Exposures.” *Journal of Exposure Analysis and Environmental Epidemiology*. 8(1):17-35.

Mackey, P., Aschengrau, A., Balasko, C., Pultinas, D., Hardy, S., (1996) “Blood Lead Levels Following Environmental Intervention Study,” Final Report on Grant H64/CCH108235-03 to U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, Environmental Hazards & Health Effects, Childhood Lead Poisoning Prevention.

Marcus, A.H., (1985) “Multicompartment Kinetics Models for Lead. I. Bone Diffusion Models for Long-term Retention.” *Environmental Research*. 36: 441-458.

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

Markowitz, M.E., Bijur, P.E., Ruff, H.A., Balbi, K., and Rosen, J.F., (1996) “Moderate Lead Poisoning: Trends in Blood Lead Levels in Unrelated Children.” *Environmental Health Perspectives*. 104(9):968-972. September 1996.

Markowitz, M.E., (1998) Personal Communication. February 1998.

Maryland Department of the Environment (1995) Final Report on Grant H64/CCH 30 7067-03 to U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, Environmental Hazards & Health Effects, Childhood Lead Poisoning Prevention. March 1995.

Mielke, H.W., Adams, J.E., Huff, B., Pepersack, J., Reagan, P.L., Stoppel, D., Mielke, P.W., Jr., (1994) "Dust Control as a Means of Reducing Inner-City Childhood Pb Exposure." *Trace Substances in Environmental Health*. Volume XXV:121-128.

The National Center for Lead-Safe Housing and The University of Cincinnati Department of Environment Health. (1997) "Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program," Fourth Interim Report. Prepared for U.S. Department of Housing and Urban Development. March 1997.

The National Center for Lead-Safe Housing and The University of Cincinnati Department of Environment Health. (1998) "Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program," Fifth Interim Report. Prepared for U.S. Department of Housing and Urban Development. March 1998.

The National Institute for Occupational Safety and Health. (1992) "Evaluation of the HUD Lead-Based Paint Abatement Demonstration Project," Prepared for U.S. Department of Housing and Urban Development. HETA 90-070-2181. February 1992.

Nedellec, V., Fontaine, A., Luciolli, E., Bourdillon, F., (1995) "Evaluation of Abatement Interventions in 59 Homes of Lead Poisoned Children," *Rev. Epidem. Et Sante Publ*. 43:485-493.

Nilsson, U., Attewell, R., Christoffersson, J.O., Schutz, A., Ahlgren, S., Skerfving, S., and Mattson, S., (1991) "Kinetics of Lead in Bone and Blood after End of Occupational Exposure." *Pharmacology and Toxicology*. 69: 477-484.

Nordberg, G.R., Mahaffey, K.R., and Fowler, B.A., (1991) "Introduction and Summary. International Workshop on Lead in Bone: Implications for Dosimetry and Toxicology." *Environmental Health Perspectives*. 91:3-7.

Rabin, R., Brooks, D.R., and Davis, L.K. (1994) "Elevated Blood Lead Levels among Construction Workers in the Massachusetts Occupational Lead Registry." *American Journal of Public Health*. 84:1483-1485.

Rabinowitz, M.B., Wetherill, G.W., Kopple, J.D., (1973) "Lead Metabolism in the Normal Human: Stable Isotope Studies." *Science*. 182: 725-727.

Rabinowitz, M.B., (1991) "Toxicokinetics of Bone Lead." *Environmental Health Perspectives*. 91:33-37.

Rabinowitz, M.B., Wetherill, G.W., and Kopple, J.D., (1976) "Kinetic Analysis of Lead Metabolism in Healthy Humans." *Journal of Clinical Investigation*. 58:260-270.

Rey-Alvarez, S., and Menke-Hargrave, T. (1987) "Deleading Dilemma: Pitfall in Management of Childhood Lead Poisoning." *Pediatrics*. 79:214-217.

Rhoads, G.G., Ettinger, A.S., Goldman, K.D., Weisel, C.P., Buckley, T.J., and Lioy, P.J., (1996), "The Effect of a Dust Lead Control Program Combined with Health Education on Blood Lead in Toddler: A Randomized Study," (Abstract) Submitted for Presentation at the Annual Conference of the *American Public Health Association*, November 1996.

Rhoads, G.G., Ettinger, A.S., Weisel, C.P., Buckley, T.J., Goldman, K.D., Adgate, J., Lioy, P.J., (1999) "The Effect of Dust Control on Blood Lead in Toddlers: A Randomized Trial." *Pediatrics*. 103(3):551-555.

Roberts, J.W., Camann, D.E., and 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.

Rosen, J., Markowitz, M., Bijur, P., Jenks, S., Wielopolski, L., Kalef-Ezra, P., and Slatkin, D., (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.

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.

Rust, S.W., Kumar, P., Burgoon, D.A., Niemuth, N.A., and Schultz, B., (1999) "Influence of Bone-lead Stores on Lead Hazard Intervention." *Environmental Research* (in press).

Schroeder, H.A., Tipton, I.H., (1968) "The Human Body Burden of Lead." *Archives of Environmental Health*. 17:965-977.

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. Also see EPA 1996d.

Schultz, B.D., Peppard, P.E., Kanarek, M.S., Murphy, A., White, K.K., and Stroup, C.R., (1998) "A Prospective Study of the Effectiveness of In-Home Educational Visits to Reduce Lead Levels in Children." Draft manuscript.

Schultz, B.D., Pawel, D., and Murphy, A., (1999) "A Retrospective Examination of In-Home Educational Visits to Reduce Childhood Lead Levels." *Environmental Research* (in press).

Schutz, A., Skerfving, S., Ranstam, J., and Christoffersson, J., (1987) "Kinetics of Lead in Blood after the End of Occupational Exposure." *Scand. J. Work Environ. Health*. 13:221-231.

Schwartz, J., (1994) “Low-level lead exposure and children's IQ: A meta-analysis and search for a threshold.” *Environmental Research*. 64:42-55.

Smith, D.R., Osterloh, J.D., Flegal, A.R., (1996) “Use of Endogenous Stable Lead Isotopes to Determine Release of Lead from the Skeleton.” *Environmental Health Perspectives*. 104(1):60-66.

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.

Staes, C., and Rinehart, R., (1995) “Does Residential Lead-Based Paint Hazard Control Work?” Report to National Center for Lead-Safe Housing, April 1995.

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.

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

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

U.S. Department of Housing and Urban Development (1995) “Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing”. Office of Lead-Based Paint Abatement and Poisoning Prevention, Washington, D.C., 1995.

U.S. Department of Labor (1993) “Lead Exposure in Construction; Interim Final Rule.” *Federal Register*. 88(84):26590-26649.

U.S. Environmental Protection Agency (1986) “Air Quality Criteria for Lead.” Environmental Criteria and Assessment Office, USEPA, Research Triangle Park, NC. Volumes I-IV.

U.S. Environmental Protection Agency (1987) “Baltimore Integrated Environmental Management Project - Phase II Report: Reducing the Hazards from Abatement of Lead Paint.” Final Report.

U.S. Environmental Protection Agency (1993a) “Urban Soil Lead Abatement Demonstration Project, Volume II: Boston Report (2 Parts),” EPA Report 600/AP-93/001b.

U.S. Environmental Protection Agency (1993b) “Urban Soil Lead Abatement Demonstration Project, Volume III: Baltimore Report (2 Parts),” EPA Report 600/AP-93/001c.

U.S. Environmental Protection Agency (1993c) “Urban Soil Lead Abatement Demonstration Project, Volume IV: Cincinnati Report,” EPA Report 600/AP-93/001d.

U.S. Environmental Protection Agency (1995a), “Review of Studies Addressing Lead Abatement Effectiveness,” EPA Report 747-R-95-006.

U.S. Environmental Protection Agency (1995b), “Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Pre-Intervention Findings”, EPA Report 747-R-95-012.

U.S. Environmental Protection Agency (1995c), “Seasonal Rhythm of Blood-Lead Levels: Boston, 1979-1983,” EPA Report 747-R-94-003.

U.S. Environmental Protection Agency (1996a), “Comprehensive Abatement Performance Study, Volume I: Summary Report,” EPA Report 230-R-94-013a.

U.S. Environmental Protection Agency (1996b), “Comprehensive Abatement Performance Study, Volume II: Detailed Statistical Results,” EPA Report 230-R-94-013b.

U.S. Environmental Protection Agency (1996c), “Effect of In-Home Educational Intervention on Children’s Blood Lead Levels in Milwaukee,” EPA Report 747-R-95-009.

U.S. Environmental Protection Agency (1996d), “Seasonal Trends in Blood Lead Levels in Milwaukee,” EPA Report 747-R-95-010.

U.S. Environmental Protection Agency (1996e) “Urban Soil Lead Abatement Demonstration Project, Volume I: EPA Integrated Report,” EPA Report 600/P-93/001aF.

U.S. Environmental Protection Agency (1997), “Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on the First Year of Follow-up”, EPA Report 747-R-97-001.

U.S. Environmental Protection Agency (1998a), “Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on Two Years of Follow-up”, EPA Report 747-R-97-005.

U.S. Environmental Protection Agency (1998b), “Risk Analysis to Support Standards for Lead in Paint, Dust, and Soil,” EPA Report 747-R-97-006.

Wedeen, R.P., (1988) “Bone Lead, Hypertension, and Lead Nephropathy.” *Environmental Health Perspectives*. 78:57-60.

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.

Wrenn, M.E., Cohen, M., Rosen, J.C., Eisenbud, M., Blanchard, R.L., (1972) “In-vivo Measurements of Lead-210 in Man. Assessment of Radioactive Contamination in Man.” IAEA. pp 129-146.

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APPENDIX A

ABSTRACTS OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS

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A.1. New York Paint Abatement Study

Reference. Markowitz, M.E., Bijur, P.E., Ruff, H.A., Balbi, K., and Rosen, J.F. (1996) "Moderate Lead Poisoning: Trends in Blood Lead Levels in Unchelated Children." *Environmental Health Perspectives*. 104(9):968-972.

Markowitz, M.E. (1998) Personal Communication. February 1998.

Pertinent Study Objectives. This study sought to determine the effectiveness of a combination of remediation of household lead hazards, educational intervention strategies, and iron therapy on reducing blood-lead levels (PbB) in moderately lead poisoned children (25-55 µg/dL) in the absence of chelation therapy.

Sampled Population. The sample population consisted of 206 children who were referred to the Montefiore Medical Center Lead Clinic and identified as having moderately elevated blood-lead concentrations (25-55 µg/dL) between 1986 and 1992. All of the children received a lead mobilization test with negative results, indicating none were qualified to receive chelation therapy. Of the 206 children enrolled, 93 underwent chelation therapy at least once, and only 79 of the remaining 113 children completed the study. The final study population consisted of 79 children ranging in age from 1 to 7 years (mean: 31.5 months at enrollment) with moderately elevated blood-lead levels, who had not received chelation therapy prior to or during the study. Approximately two-thirds of the children were of Hispanic origin and one-third were African American.

Intervention Strategy. Following inspection of the homes, the local Board of Health's Lead Bureau was notified to start the legal process needed to bring the home into compliance with existing health and housing codes. No specific abatement protocol was enforced. Education on sources of lead, its toxicity, and methods to reduce exposure to children was begun at the first clinic visit. Efforts were also made to reduce the child's exposure to lead hazards by placement in alternative lead-free housing during abatement of the child's residence. Nutritional counseling was begun at the first clinic visit. Parents of children with ferritin levels less than 16 µg/L at enrollment were given supplies to provide their child with 5-6 mg/kg of elemental iron daily for 3 months.

Measurements Taken. Lead content of paint was measured by x-ray fluorescence (XRF) using an XK-3 instrument (Princeton Gamma Tech). The blood-lead concentrations were collected via venipuncture and measured by graphite furnace atomic absorption spectrometry using a Varian Techtron atomic absorption spectrophotometer. Ferritin was measured by radioimmunoassay in sera.

Study Design. In this study, moderately Pb-poisoned children (25-55 µg/dL) were followed for 6 months. Eligible Children received the following interventions: notification of the health department to remediate lead hazards; reinforced educational efforts about the toxicity sources and treatment of Pb during 10 clinic and 3 home visits; and iron therapy for children with ferritin levels less than16 µg/L. Ten clinic visits scheduled during the 6 months occurred at: enrollment, and 1, 4, 6, 7, 12, 16, 20, 24, and 25 weeks later for each child. The three home visits occurred at: enrollment, 6 weeks, and at 24-25 weeks during the study. Primary outcome measurements were Blood -lead levels, ferritin levels and home environmental score (HES). Blood-lead levels were obtained at each clinic visit and ferritin levels were taken at 1, 7, and 24 weeks clinic visit. At each home visit, each household was given a home environmental score (HES). This score consisted of a combination of the household's paint status and XRF value. Each painted surface was given a visual rating for its condition on a scale of 0 to 3. A score of 0 was given to an intact surface, 1 if the surface had bubbles, 2 to a surface with cracks, and 3 to a surface with peeling paint. Each surface of each room was tested in triplicate at one location per surface for its lead content. Surfaces tested included all walls, windows, doors, and baseboards. The XRF instrument was calibrated hourly during the testing.

Study Results. The mean of the triplicate readings was calculated for each surface and then multiplied by the visual rating score. The HES given to each individual household is the sum of these products. Mean HES scores decreased throughout the study (Table A.1-1). At enrollment, ten percent of households had a HES of 0, whereas 25 percent had a HES of 0 at 6 weeks, and 20 percent had a HES of 0 at 6 months. The median HES score of 37 at the time of enrollment was used as a reference point to categorize the population into high- and low-level lead exposure.

Table A.1-1. Home Environmental Scores (HES) by Time

Time	Minimum	Maximum	Mean ± SE	Median
Enrollment	0	830	88 ± 16	37
Week 6	0	766	44 ± 11	14
Week 24	0	294	27 ± 5	17

Mean blood-lead concentrations were greater for children with high HES scores (i.e., > 37) than for children with low HES scores. A significant correlation was found between PbB and HES at enrollment only (correlation=0.243, n=77, $p<0.05$). Table A.1-2 displays the frequency distribution for the high- and low-level HES groups by blood-lead level at enrollment and at week 25. Average blood-lead levels declined for both HES groups throughout the course of the study (Table A.1-3). By 6 months post-intervention, blood-lead levels had declined to less than 25 µg/dL for two-thirds of the children, regardless of initial HES status. Only 7% of the children's blood-lead levels were less than 15 µg/dL at the end of the study, with the minimum blood-lead level at 9 µg/dL.

Table A.1-2. Frequency Distribution for the High- and Low-Level HES Groups by Blood-Lead Level at Enrollment and Week 25

PbB (µg/dL)	HES ≤ 37		HES > 37	
	Enrollment	Week 25	Enrollment	Week 25
< 15	0	14	0	0
15-24	5	53	0	67
25-34	90	31	80	30
35-44	5	0	15	3
> 44	0	3	5	0

Table A.1-3. Average Blood-Lead Levels (µg/dL) by Children Grouped in High- and Low-Level HES Scores

Week of Study	HES ≤ 37 (n = 40)		HES > 37 (n = 39)	
	Mean	Standard Deviation	Mean	Standard Deviation
0	25	3	31	5
1	26	4	29	5
4	25	7	27	5
6	24	5	26	5
7	24	6	26	4
12	23	5	25	5
16	22	5	25	4
20	21	6	22	5
24	21	7	23	5
25	21	7	23	4

Two subgroups consisting of 10 children each whose HES scores were consistently above or consistently below the initial median HES score of 37 were chosen for further analysis. Children who were consistently above the median HES score had higher initial blood-lead levels than those who were consistently below the median HES score. However, mean blood-lead concentrations for both subgroups declined at a similar rate (Table A.1-4) over the 6 months of the study.

Table A.1-4. Average Blood-Lead Levels (µg/dL) by Children Grouped in Consistently High- and Consistently Low-Level HES Scores

Week of Study	Consistently Below HES Score of 37 (n = 10)		Consistently Above HES Score of 37 (n = 10)	
	Mean	Standard Deviation	Mean	Standard Deviation
0	27	3	35	8
1	25	3	31	4
4	21	5	28	5
6	23	6	26	6
7	22	6	28	5
12	20	4	25	6
16	21	5	24	5
20	21	4	22	4
24	17	6	23	7
25	18	5	23	4

Conclusions (including caveats). These results suggest that a combination of source abatement, educational intervention strategies, and iron therapy result in a 27 percent reduction in blood-lead for children with moderately (22-55 µg/dL) elevated blood-lead levels. The magnitude of the reduction in children's blood-lead levels may be confounded with the effects of seasonal variation and the age of the child. Also, the authors conclude that no attempt was made to quantify the amount of time the child spent in the primary residence and other secondary residences. Although one measure of exposure was examined (HES), no measures were reported for the dust-lead content in the household and on the child's hands.

A.2. Baltimore Three-City Soil Abatement Study

Reference. U.S. Environmental Protection Agency (1996e), "Urban Soil Lead Abatement Demonstration Project, Volume I: EPA Integrated Report," EPA Report 600/P-93/001aF.

U.S. Environmental Protection Agency (1993b), "Urban Soil Lead Abatement Demonstration Project, Volume III: Baltimore Report (2 Parts)," EPA Report 600/AP-93/001c.

Pertinent Study Objectives. Baltimore was one of three urban cities participating in a project examining whether a reduction in residential soil-lead concentration would result in a statistically significant decrease of blood lead levels among children residing in the target homes. Each community also included specific objectives of its own to the project. For the Baltimore study, there was also interest in whether decreasing soil-lead levels would result in a corresponding decrease in household dust-lead levels.

Sampled Population. Baltimore children aged 6 to 72 months residing in otherwise comparable communities designated the control or study areas. The designated areas were chosen for comparable demographic, soil lead and housing characteristics. An initial sample size of 408 children were chosen, with a total attrition of 294 children and total gain of 71 children through 6 rounds of blood sampling. Sample sizes immediately prior to and after interventions were 270 children (round 3) and 197 children (round 4).

Intervention Strategy. For the study group, the top 6 inches of soil in areas with lead concentration greater than 550 ppm were removed and replaced with clean soil (i.e., less than 50 ppm). For both groups, paint stabilization via removal and repainting was implemented to prevent recontamination of the cleaned soil.

Measurements Taken. Exterior and interior paint chip samples were collected and analyzed via X-Ray Fluorescence (XRF). Soil core samples were collected and analyzed via energy dispersive x-ray spectrometry. Interior vacuumed dust samples were collected and analyzed via wet digestion atomic absorption spectrophotometry and laboratory XRF. First flush kitchen cold tap water samples were collected and analyzed via graphite furnace atomic absorption spectrophotometry. Venipuncture blood lead samples were collected from all participating children and analyzed via anodic stripping voltammetry. Wet wipe hand lead samples were collected from all participating children and analyzed via atomic absorption spectrophotometry.

Study Design. The study took place over the course of 3 years, beginning in the fall of 1988. Otherwise comparable study areas were designated as treatment and control areas. Study homes in the treatment area received both soil abatement and paint stabilization interventions. Control homes received only paint stabilization. Children with moderately elevated blood-lead levels were enrolled in the study. Progress was measured through six rounds of sampling. The interventions occurred between rounds 3 and 4, and began in the summer and fall of 1990. Data gathered were of 3 groups: environmental (soil-, dust-, paint- and water-lead levels), biological (blood- and hand- lead levels) and questionnaire data. Environmental data were obtained only before and after the soil abatements. Biological and questionnaire data were collected every round. Primary outcome measurements were blood-lead concentrations, soil-lead concentrations and dust-lead loading.

Study Results. Although there was a statistically significant difference in study area soil-lead concentrations before and after abatement (decrease of 470.1 ppm), the decrease in dust lead level was not statistically significant for the study area, but was statistically significant for the control area. Dust and soil lead changes are summarized in Table A.2-1.

Table A.2-1. Pre- and Post-Intervention Mean Soil-Lead Concentration and Dust-Lead Loading*

	Group	Pre-Intervention Mean (SE)	Post-Intervention Mean (SE)	Mean Difference (SE)
Soil-Lead Concentration (ppm)	Treatment n = 57	503.6 (268.2)	33.6 (34.9)	470.1 (269.8)
	Control n = 147	501.3 (312.1)	-	-
Dust-Lead Loading (µg/ft²)	Treatment n = 33	165.8 (217.5)	90.7 (86.3)	75.1 (192.1)
	Control n = 40	162.7 (294.4)	103.0 (137.6)	59.7 (287.0)

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

As for the effects on blood-lead concentration, a decrease in blood-lead concentration for the study and control areas were observed at round 4, January through March of 1990, three months following intervention. In round 5, May through July, blood-lead levels increased slightly for both groups, remaining somewhat stable through round 6.

Six linear regression models, with the log of blood-lead level or the log of hand-lead level as the response variable, were constructed; the independent variables included treatment group, socio-economic status, gender, age, season, dust-lead level, and soil-lead level. For each model, regression coefficients were calculated for all six rounds, and separately for children who did and did not participate in all six rounds. The most relevant model, Model 1, measures the direct effect of group assignment (treatment or control) on the log of blood lead:

$$LPbB_{ij} = b_{0j}T_i + b_{1j}C_i + e_{ij}$$

where for the ith child in round j,

$LpbB_{ij}$ = log of blood lead of child i in round j
T_i = 1 if child i is in treatment group, else 0
C_i = 1 if child i is in control group, else 0
e_{ij} = error term.

The model-predicted geometric mean of the blood-lead levels, for children participating in all six rounds, decreased from 9.44 µg/dL in round 3 to 8.36 µg/dL in round 4 for the treatment group and 9.28 µg/dL in round 3 to 7.59 µg/dL in round 4 for the control group. Thus, a child assigned to the treatment group will have a decrease (from round 3 to 4) in blood-lead level of 11% versus a decrease of 18% for a child assigned to the control group. For the remaining two rounds, the geometric mean log blood-lead levels for the control group remained lower than for the study group, although the differences were not statistically significant. See Table A.2-2 for a summary of the geometric mean blood-lead levels for the subset of children who participated in all six rounds.

Table A.2-2. Model-Predicted Geometric Mean Blood-Lead Concentrations for Children Participating In All Six Rounds

Round	Geometric Mean of Blood Lead (µg/dL)	
	Treatment Group (SE)	Control Group (SE)
1	11.858 (0.7697)	11.3362 (0.60082)
2	10.8374 (0.67408)	10.2472 (0.50939)
3*	9.4404 (0.62156)	9.2813 (0.52328)
4	8.3602 (0.56731)	7.5989 (0.44263)
5	8.8375 90.59591)	8.0688 (0.4763)
6	9.3371 (0.61149)	8.3562 (0.5114)

* Interventions were conducted between rounds 3 and 4.

Conclusions (including caveats). The results indicate soil abatement did not produce significant declines in the mean blood-lead concentrations of children benefitting from the abatements. The authors hypothesize that perhaps this was due in part to the low levels of soil lead in the study area. Nevertheless, soil abatement seems not to be an effective method for lowering the blood-lead levels of urban children. It could be, however, that soil abatement might serve as a helpful adjunct. Also worth noting is that paint stabilization, which by itself could be considered a "treatment", was provided to both groups. Thus, it could be argued that no true control group was used. Perhaps the lack of a statistically significant difference in the mean log of blood-lead level between the control and treatment group are due to the effects of paint stabilization. As for the 12 sets of coefficients (6 rounds, 2 subsets of children participating/not participating in all 6 rounds) given for each of the 6 models, perhaps a more useful approach would be 1 set of coefficients per model. The 12 sets of coefficients and the 6 error terms per child results in a lack of independence amongst the error terms, violating the usual assumption of independent error terms for linear models.

A.3. Cincinnati Three-City Soil Abatement Study

Reference. U.S. Environmental Protection Agency (1996e), "Urban Soil Lead Abatement Demonstration Project, Volume I: EPA Integrated Report," EPA Report 600/P-93/001aF.

U.S. Environmental Protection Agency (1993c), "Urban Soil Lead Abatement Demonstration Project, Volume IV: Cincinnati Report," EPA Report 600/AP-93/001d.

Pertinent Study Objectives. Cincinnati was one of three urban communities participating in an EPA project examining whether reduction of soil and dust-lead levels would result in a statistically significant decrease in blood lead levels of children. There was also interest in whether interim interior dust abatement, in conjunction with exterior dust and soil abatement would result in a greater reduction in blood lead than either alone.

Sampled Population. Families of children under 5 years of age were recruited from three study areas (A, B, and C) selected for similar demographic and housing characteristics. Also, areas chosen primarily consisted of rehabilitated housing in which lead-based paint was abated as a result of Department of Housing and Urban Development-supported programs in the early 1970s. Rehabilitation involved the "gutting" of buildings, the complete replacement of plumbing, wiring, and heating systems, and installation of new walls, flooring, windows, and doors. Two hundred and twenty-five children were enrolled in phase 1 (June and July of 1989), of which 173 resided in rehabilitated housing. One hundred of the initial 225 remained at the completion of the study in October 1991. Also, 66 phase 5 recruits (January of 1990), of which 37 remained, and 16 new births contributed to a final tally of 153 participants at the end of the study.

Intervention Strategy. Area A received soil lead, exterior dust, and interior dust abatement treatments in 1989. Soil lead abatement consisted of the removal of the top 6 inches of soil if the 15 cm core average or top 2 cm lead concentration was greater than or equal to 500 ppm. Interior dust abatement consisted of vacuuming and/or wet cleaning surfaces including ledges, window wells and window sills, and non-carpeted floors. Contaminated carpets and selected furniture were replaced as vacuuming was determined ineffective for abatement. Exterior dust abatement consisted of vacuuming paved areas.

Measurements Taken. Vacuumed exterior dust and surface and core soil samples were analyzed via x-ray fluorescence (XRF). Air sampled interior dust samples were digested and analyzed by flame atomic absorption spectroscopy (AAS). 30-minute and overnight stagnation water samples were analyzed using $Mg(NO_3)_2$ and NH_4HP0_4 as matrix modifiers and on a Perkin-Elmer Graphite Furnace Atomic Absorption Spectrometer with Zeeman background correction. "Wet Wipes" hand samples were analyzed with flame AAS. Paint samples were analyzed via XRF.

Study Design. The study took place through 9 phases of environmental and biological monitoring.. An earlier "phase", phase 00, involved the project's design and initial measurements. Table A.3-1 presents a schedule of the sequential phases. Interior and exterior dust and soil abatement for Area A and interior dust abatement for Area B took place between phases 1 and 2. Exterior dust and soil abatement for Area B took place between phases 5 and 6. Area C served as a control, although all three forms of abatement were provided after phase 9. In this study, interventions were assigned based on the location of the home in one of three neighborhoods. Primary outcome measurements were soil lead concentrations, dust lead loadings, dust lead concentrations, and blood-lead concentrations

Table A.3-1. Schedule of Phases

Phase	0	1	2	3	4	5	6	7	8	9
Time	9/88-5/89	6&7/89	9&10/89	11/89	2/90	6/90	9/90	11/90	2/91	6/91

Study Results. For Area A, the geometric mean soil-lead concentration decreased, between phases 00 and 05, from 200 ppm to 54 ppm, for the top 2 cm core composite samples. This decrease was statistically significant ($p < 0.05$). For Area B, the geometric mean soil-lead concentration for the top 2 cm core composite samples decreased from 161 ppm in phase 05 to 59.5 ppm in phase 09. The geometric mean soil lead concentration changes for the top 2 cm core composite samples, as reported for each study area and phase, are summarized in Table A.3-2.

Table A.3-2. Geometric Mean Soil Lead Concentration (ppm) for Top 2 cm Core Composite Samples

Phase	Area A (95% C.I.)	Area B (95% C.I.)	Area C (95% C.I.)
0	200 (162-245)	103 (91-116)	140 (119-164)
	Soil Abatement		
2	54 (46.1 -63.3)	148 (133-163)	163 (139-191)
5	51.8 (44.3-60.7)	161 (144-180)	145 (124-169)
		Soil Abatement	
9	58.8 (49.7-69.7)	59.5 (54.5-64.9)	161 (137-190)
			Soil Abatement

The geometric means of the interior entry dust lead concentration for both Areas A and B (initial recruits living in rehabilitated housing and participating in both phases) increased after interior dust abatement (between phases 01 and 02). However, the geometric mean dust-lead loadings decreased for both groups. As might be expected, exterior dust abatement produced no discernible effect on dust-lead concentration. Exterior and interior dust abatement results are summarized in Tables A.3-3a, A.3-3b, A.3-4.

Table A.3-3a. Geometric Mean Interior Entry-Dust Lead Loading (µg/ft²) and Concentration (ppm) for Initial Recruits Living in Rehabilitated Housing and Participating in Both Phases 1 and 2

Phase	Area A		Area B		Area C	
	Concentration	Loading	Concentration	Loading	Concentration	Loading
1	323 (221-472)	42.94 (11.62-158.76)	547 (421-711)	22.49 (11.62-43.69)	278 (192-403)	12.73 (6.13-26.31)
2	757 (552-1,038)	25.93 (9.11-73.8)	614 (517-729)	5.02 (3.44-7.34)	36 (255-508)	10.04 (5.76-17.38)

(95% C.I.)

Table A.3-3b. Geometric Mean Interior Entry Dust-Lead Loading (µg/ft²) and Concentration (ppm) for Initial Recruits Living in Rehabilitated Housing and Participating in Both Phases 1 and 9

Phase	Area A		Area B		Area C	
	Concentration	Loading	Concentration	Loading	Concentration	Loading
1	351 (244-506)	19.43 (3.53-107.27)	430 (321-577)	17.29 (7.71-38.95)	215 (122-378)	11.06 (4.83-25.28)
9	591 (371-942)	24.17 (8.55-68.23)	515 (411-645)	29.65 (15.24-57.63)	324 (255-410)	34.11 (12.92-89.88)

(95% C.I.)

Table A.3-4. Geometric Means Exterior Dust-Lead Concentration (ppm) for All Locations

Phase	Area A	Area B	Area C
1	1,314 (1,151-1,500)	1,905 (1,683-2,156)	586 (493-697)
	Exterior Abatement		
2	1,707 (1,530-1,905)	1,793 (1,615-1, 991)	520 (457-612)
5	1,312 (1,128-1,526)	1,970 (1,744-2,226)	594 (501-703)
		Exterior Abatement	
6	1,184 (1,025-1,369)	1,954 (1,745-2,188)	581 (490-690)

(95% C.I.)

The mean differences in blood-lead concentrations measured between phases 1 and 9 were 0.64, -2.04, and -1.72 (µg Pb/dL) for Areas A, B and C, respectively. The difference between the decreases in Areas A and B was statistically significant (level of significance not provided by the authors). Results were for initial recruits living in rehabilitated housing and participating in both phases. Measured differences in blood lead levels between phases are summarized in Table A.3-5.

Table A.3-5. Mean Differences in Blood Lead Levels (µg/dL) Between Phases for Initial Recruits Living in Rehabilitated Housing and Participating in Compared Phases

Compared Phases	A	Area A (95% C.I.)	B	Area B (95% C.I.)	C	Area C (95% C.I.)
3 to 1	10.42	-1.86 (-3.07 to - 0.65) n = 50	13.05	-1.86 (-2.61 to -1.11) n = 77	9.47	-2.55 (-3.61 to -1.44) n = 47
5 to 1	9.63	0.87 (-0.8 to 2.54) n = 43	12.54	-1.51 (-2.81 to -0.22) n = 61	9.35	-0.96 (-2.47 to 0.54) n = 41
7 to 1	9.38	0.76 (-1.16 to 2.67) n = 32	12.15	-2.46 (-3.75 to -1.17) n = 53	9.36	-1.5 (-2.93 to -0.07) n = 33
9 to 1	9.44	0.64 (-1.86 to 3.14) n = 27	12.38	-2.04 (-3.35 to -0.73) n = 48	9.96	-1.72 (-3.53 to 0.09) n = 26

A = Area A Phase 1 Mean for children participating in both phases
B = Area B Phase 1 Mean for children participating in both phases
C = Area C Phase 1 Mean for children participating in both phases

Conclusions (including caveats). Results indicate soil abatement can be effective in the long-term for reducing lead levels in soil. However, there is no conclusive evidence that the abatement methods chosen were effective in long-term reduction of interior and exterior dust lead. More importantly, there is no evidence that the three forms of abatement together reduces blood lead level in the long term nor is there evidence that such an abatement method is more effective than interior dust abatement alone. Also, seasonal fluctuations should be noted when considering changes in blood lead-levels. For example, phase 1 was conducted in June of 1989 while phase 3 was conducted in November of 1989. Thus, decreases in blood lead level as indicated in Table A.3-5 could have been in part due to seasonal variation.

A.4. Boston Three-City Soil Abatement Study

Reference. U.S. Environmental Protection Agency (1996e), "Urban Soil Lead Abatement Demonstration Project, Volume I: EPA Integrated Report," EPA Report 600/P-93/001aF.

U.S. Environmental Protection Agency (1993a), "Urban Soil Lead Abatement Demonstration Project, Volume II: Boston Report (2 Parts)," EPA Report 600/AP-93/001b.

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.

Aschengrau, A., Beiser, A., Bellinger, D., Copenhafer, D., Weitzman, M. (1997) "Residential Lead-Based-Paint Hazard Remediation and Soil Lead Abatement: Their Impact among Children with Mildly Elevated Blood Lead Levels." *American Journal of Public Health*. 87(10):1698-1702.

Note: This summary was prepared from the papers listed above, two of which were available before the study report was published.

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 and to assess the impact of residential lead-based paint hazard remediation alone and in combination with soil abatement on children with mildly elevated blood-lead levels.

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
- 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; 3) extensive soil abatement; and, finally, 4) 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. Interior dust abatement consisted of HEPA vacuuming walls, woodwork, floors, and rugs, wiping surfaces with wet cloths and furniture with oil-treated cloths. Soil abatement consisted of removing surface soil to a depth of 6 in., installing geotextile fabrics, replacing with top soil containing minimum lead levels, and installing ground cover. Lead-based paint abatement was conducted on exterior and interior areas where x-ray fluorescence readings exceeded 1.2 mg/cm² or a sodium sulfide chemical reaction was positive. For both interior and exterior areas, deleading consisted of removing leaded paint from mouthable surfaces below 5 feet and making intact all paint above 5 feet. Occupants and their belongings were relocated off site during the interior remediations. Reoccupancy was permitted only if dust-lead levels in clearance wipe samples were below 200, 500, and 800 µg/ft² on floors, window sills, and window wells, respectively. Additional cleanups were conducted until these criteria were met.

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;
- an assessment of sources of lead exposure and behavioral factors related to lead exposure was conducted at each blood draw; and,
- hand-wipe samples.

Soil and dust samples were analyzed by x-ray fluorescence. Blood-lead levels were determined by graphite furnace atomic absorption spectrometry.

Study Design. This study was a randomized controlled trial of the effects of lead-contaminated soil abatement on blood lead levels of children followed up for approximately 1 year after the intervention. The interventions were soil abatement, interior dust abatement and loose paint removal. Children were randomized to one of three groups: the study group, whose homes received soil and interior dust abatement and loose paint removal; comparison group A, whose homes received interior dust abatement and loose paint removal; and comparison group B, whose homes received only interior loose paint removal. Main outcome measurements were blood lead levels from pre-abatement and blood lead levels approximately 6 and 11 months after abatement. Table A.4-1 summarizes the interventions and timing for each experimental group.

Table A.4-1. 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

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

Study Results. For children whose premise underwent soil abatement but not lead-based paint abatement, mean blood-lead concentrations decreased between pre- and post-intervention measures (Table A.4-2). 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.4-2. Blood-Lead Concentration (µg/dL) by Experimental Group for Children Whose Homes Received Soil Abatement, but not Lead-Based Paint Abatement

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

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 received Phase II soil abatement but not lead-based paint abatement and 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, a trend of large declines in blood-lead levels with larger initial PbB levels was observed (Table A.4-3).

Table A.4-3. Change in Blood-Lead Concentration (µg/dL) by Initial PbB and Sample Period

Initial PbB (µg/dL)	Change in PbB for		Overall Percentile 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%

Following Phase II interventions, mean blood-lead concentrations of Study Group children whose homes received paint hazard remediation during Phase II were an average of 2.6 µg/dL higher than those of children who received no Phase II interventions. Mean blood-lead concentrations for children whose homes received both paint hazard remediation and soil abatement during Phase II were an average of 1.4 µg/dL higher than that of children whose homes received soil abatement only (Comparison Groups A and B combined) (Table A.4-4).

Table A.4-4. Phase II Change in Blood-Lead Concentration (µg/dL) by Experimental Group and Interventions Performed

Group	Subset	Sample Size	Mean PbB Before Phase II Intervention(s) (µg/dL)	Mean PbB Following Phase II Intervention(s) (µg/dL)	Mean Change in Blood-Lead Levels
Study Group*	Paint Hazard Remediation	18	10.7	11.1	0.4
	No Paint Hazard Remediation	13	10.8	8.5	-2.2
Comparison Groups A and B Combined*	Paint Hazard Remediation and Soil Abatement	25	11.2	9	-2.2
	Soil Abatement only	31	11.9	8.3	-3.6

* Only paint hazard remediation was conducted during Phase II for the Study Group; soil abatement was conducted during Phase I. For Comparison Groups A and B, both paint hazard remediation and soil abatement were conducted during Phase II.

To evaluate the effectiveness of lead-based paint abatement, a multivariate model analysis was conducted for comparison of Phase II post-intervention blood-lead concentrations to Phase II pre-intervention blood-lead concentrations. After controlling for confounding factors in the model (e.g., age, sex, race, socioeconomic status, mouthing, hand-washing, housing characteristics, and environmental sources of lead), paint hazard remediation was associated with a statistically significant (p=0.05) increase of 6.5 µg/dL in blood-lead levels in the Study Group. Paint hazard remediation was associated with an increase of 0.9 µg/dL in blood-lead levels (p=0.36) in Comparison Group A and B homes that received paint and soil abatement, compared to those that received only soil abatement.

Although mean floor dust-lead loading levels showed an increase in all households following the Phase II interventions, the increase was greater for homes that received paint hazard remediation. Mean floor dust levels increased by 142% for Study Group households that received paint interventions and by 75% for those not receiving paint interventions. Comparison Groups A and B combined showed an increase of 42% for homes receiving paint and soil abatement and by 33% for homes receiving only soil abatement. Mean post-intervention window sill dust-lead loading levels increased by 105% for the Study Group and remained unchanged (+2%) for Comparison Groups A and B combined for those homes receiving paint hazard remediation, but decreased in homes that did not (-42% for the Study Group and -41% for Comparison Groups A and B combined).

Additional detail on environmental lead levels was reported (Aschengrau, et al., 1994) for homes that received soil abatement but not lead-based paint abatement (Tables A.4-5 through A.4-7). Although many yards had evidence of recontamination at both 6-10 and 18-22 months post-abatement, follow-up median soil-lead concentrations were generally less than 300 ppm (Table A.4-5). Floor dust samples from within the residence were composited to produce a single dust measure for each residence. Floor dust-lead loadings declined significantly during the study (Table A.4-6). Mean floor dust-lead loadings at 6-12 months post-abatement fell significantly for the Study Group ($P \leq 0.001$), but remained relatively unchanged for Comparison Groups A and B ($P=0.95$ and 0.15, respectively). 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.4-7).

Table A.4-5. Surface Soil-Lead Concentration (ppm) by Experimental Group and Sample Period for Homes that Received Soil Abatement, but not Lead-Based Paint Abatement

Group	Period	Sample Size	Geo. 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.4-6. Interior Floor Dust-Lead Loading (µg/ft²) by Experimental Group and Sample Period* for Homes that Received Soil Abatement, but not Lead-Based Paint Abatement

Group	Period	Sample Size	Geo. Mean	Std. Dev.
Study	Pre-Abate.	21	6.6	5
	6-12 months Post-Abate.	14	0.8	3.2
	18-22 months Post-Abate.	11	1.8	2.1
Comparison A	Pre-Abate.	22	2.5	2.7
	6-12 months Post-Abate.	15	2.7	2.6
	18-22 months Post-Abate.	N/A	N/A	N/A
Comparison B	Pre-Abate.	22	2.3	4.2
	6-12 months Post-Abate.	12	2.5	2.5
	18-22 months Post-Abate.	N/A	N/A	N/A

* Lead loadings converted from µg Pb per m² to µg Pb per ft².

Table A.4-7. Interior Window Well Dust-Lead Loading (µg/ft²) by Experimental Group and Sample Period* for Homes that Received Soil Abatement, but not Lead-Based Paint Abatement

Group	Period	Sample Size	Geo. Mean	Std. Dev.
Study	Pre-Abate.	19	99.5	13.3
	6-12 months Post-Abate.	15	248.3	7
	18-22 months Post-Abate.	11	271.2	3.8
Comparison A	Pre-Abate.	22	244.9	5.4
	6-12 months Post-Abate.	15	133.1	8.5
	18-22 months Post-Abate.	N/A	N/A	N/A
Comparison B	Pre-Abate.	21	185.5	5.8
	6-12 months Post-Abate.	12	321.1	9.4
	18-22 months Post-Abate.	N/A	N/A	N/A

* Lead loadings converted from µg Pb per m² to µg Pb per ft².

Conclusions (including caveats). The authors state that lead-based-paint remediation alone was associated with statistically significant blood lead increase of 6.5 µg/dL over the subsequent 9 months, but with an increase of only 0.9 µg/dL when combined with soil abatement. The beneficial impact of soil abatement may account for the smaller increase when both interventions were conducted. In Phase I, a soil lead reduction of 2060 ppm was associated with a 2.25 to 2.70 µg/dL reduction 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. The geometric mean pre-intervention soil lead concentration in the 92 study homes was 2,284 ppm, which is much greater than that observed in the Baltimore (approximately 500 ppm) and Cincinnati (100-200 ppm) Three-City studies. Furthermore, the decline is confounded with the efficacy of lead-based paint stabilization and seasonal variation in blood-lead levels.

A.5. Minneapolis Dust Intervention Study

Reference. Mielke, H.W., Adams, J.E., Huff, B., Pepersack, J., Reagan, P.L., Stoppel, D., Mielke, P.W. Jr. (1994) "Dust Control as a Means of Reducing Inner-City Childhood Pb Exposure." *Trace Substances in Environmental Health*. Volume XXV:121-128.

Pertinent Study Objectives. This study sought to reduce children's blood-lead concentrations (PbB) by reducing exterior soil and dust lead and interior dust lead at targeted residences in the Minneapolis and St. Paul, Minnesota inner-city areas.

Sampled Population. The sample population consisted of 40 primarily minority children identified by the Twin Cities Mapping Project as living in high soil-lead concentration communities. Twenty-three children from Minneapolis were targeted for treatment by the dust control intervention, whereas 17 children from St. Paul received no dust control treatment.

Intervention Strategy. For the 23 treatment group children, interior dust treatment consisted of wet wiping walls to remove loose paint chips, followed by a thorough vacuuming, using a high efficiency particle accumulator (HEPA) vacuum. Households in this group with children exhibiting the highest blood-lead concentrations were provided more intensive dust control treatment than those with children exhibiting lower concentrations. The floors were then mopped with a high phosphate detergent and some carpets were removed from the household. Interventions at the residence's exterior included covering bare soil with sod or wood chips, the addition of a sandbox, and provisions to prevent soil from washing onto sidewalks (thereby providing opportunity for dust track-in). Parents of children in the treatment group were supplied with dust control information and cleaning supplies. Only prevention information was provided to the parents of the control group children.

Measurements Taken. Venous blood samples were collected and analyzed by the Minneapolis Children's Medical Center. Soil-lead loadings were collected by a 2.5 cm deep soil scrape sample at foundation, mid-yard and street-side locations. Though dust lead samples were collected, the methods for interior dust-lead collection were not reported.

Study Design. This study was designed to test an approach that utilized interior and exterior dust control as a means of reducing lead exposure of children. Two groups of children who lived in high soil lead areas of the inner-city were recruited for the project. The Minneapolis children (N=23) were the treatment group and received the dust control intervention. The St. Paul children (N=17) were in the control group and received preventive information. Primary outcome measurements were pre-intervention blood-lead levels, post-intervention blood-lead levels and post-intervention soil-lead concentrations.

Study Results. In Minneapolis, 52% of the children's blood-lead concentration decreased, 4% increased, and 44% remained the same. For the control group, 29% of the children had a reduction in PbB, while 53% exhibited an increase, and 18% remained the same (Table A.5-1).

Table A.5-1. Distribution of Blood-Lead Concentrations (µg/dL) by Study Group and Time

Blood Lead Level (µg/dL)	Treatment Group				Control Group			
	Pre-Intervention		Post-Intervention		Pre-Intervention		Post-Intervention	
	N	%	N	%	N	%	N	%
≤6	4	17	6	26	-	-	3	18
7-10	5	22	5	22	4	24	2	11
11-14	5	22	5	22	6	35	3	18
15-19	3	13	2	9	6	35	3	18
20-24	3	13	5	22	1	6	2	11
25-29	1	4	-	-	-	-	1	6
30	2	9	-	-	-	-	3	18

By the end of the study, all children in the treatment group had blood-lead concentrations less than 25 µg/dL and the percentage of children above 14 µg/dL was reduced from 39% to 30%. Blood-lead concentrations were said to decrease/increase if the post- vs. pre-intervention concentration difference exceeded the quality control limit of 1 µg/dL. Control group children showed a definite increase in blood-lead levels. The percentage of children above 14 µg/dL increased from 41% to 53% by the end of the study, and three of these children had follow-up PbB levels of 40, 41, and 61 µg/dL (prompting medical intervention). Differences between initial and follow-up blood-lead concentrations were statistically significant ($p=0.0061$) by the Fisher-Pitman test, suggesting that dust control procedures were effective for the treatment group as compared to the control group.

Post-intervention soil-lead concentrations for the treatment group were significantly ($p=0.0005$) lower than initial concentrations (Table A.5-2). Foundation and mid-yard soil-lead levels were reduced by a factor of 3 to 4. Soil-lead loadings were also reduced for the treatment group (Table A.5-3). Post-intervention soil lead samples were not collected for the control group, but were assumed to have remained unchanged. Interior dust-lead levels were not reported.

Table A.5-2. Exterior Soil-Lead Concentration (ppm) by Location, Study Group, and Time

Media	Study Group	Timing	N	Median	Range
Foundation	Treatment	Pre-intervention	12	795	34-2,240
		Post-intervention	12	178	10-2,050
	Control	Pre-intervention	10	561	22-2,960
Mid-Yard	Treatment	Pre-intervention	12	272	6-680
		Post-intervention	12	70	6-468
	Control	Pre-intervention	10	108	44-414
Street-Side	Treatment	Pre-intervention	10	255	96-373
		Post-intervention	10	214	96-373
	Control	Pre-intervention	10	153	33-470

Table A.5-3. Exterior Dust-Lead Loading (µg/ft²) by Location, Study Group, and Time

Media	Study Group	Timing	N	Median	Range
Foundation	Treatment	Pre-intervention	12	320.8	14-904
		Post-intervention	12	72.1	4-828
	Control	Pre-intervention	10	226	9-1195
Mid-Yard	Treatment	Pre-intervention	12	109.8	2-274
		Post-intervention	12	28	2-189
	Control	Pre-intervention	10	43.1	18-167
Street-Side	Treatment	Pre-intervention	10	103.3	39-151
		Post-intervention	10	86.1	39-151
	Control	Pre-intervention	10	61.4	13-189

Conclusions (including caveats). The authors conclude that the dust control treatment program resulted in reductions in children's blood-lead concentrations for the treatment group as compared to the control group. By the end of the study, all of the children in the treatment group had blood-lead levels less than 25 µg/dL. While the changes in the blood-lead concentrations of the control group children may have been due simply to random variation, some of their reductions in PbB may have been accounted for by the information given to parents on dust control prevention. Also, some of the increases in blood-lead levels may be explained by seasonal variations, since blood-lead levels tend to increase during summer months. Interpretation of these results is difficult because interior dust-lead results were not reported. Paint stabilization may have also had an impact on children's blood-lead concentrations in the treatment group. There was also no discussion on how comparable the two different populations were (i.e., age differences, gender, etc.). Although the study had a control population, children were not randomly assigned to the treatment and control groups. Thus, differences in PbB due to the treatment are confounded with any differences between the two populations. A chi-square test of homogeneity did not detect significant differences in the initial distribution of blood-lead levels between the treatment and control populations.

A.6. <u>Paris Paint Abatement Study</u>

Reference. Nedellec, V., Fontaine, A., Luciolli, E., Bourdillon, F., (1995) "Evaluation of Abatement Interventions in 59 Homes of Lead Poisoned Children," Rev. Epidem. Et Sante Publ., 43:485-493.

Pertinent Study Objectives. This study sought to determine the effectiveness that lead-based paint abatement would have in reducing severely elevated blood-lead concentrations (PbB) in children.

Sampled Population. The sample population consisted of children less than 6 years of age who were identified as severely lead-poisoned by the Maternal and Child Care Centers (PHI) of Paris between January 1990 and February 1992. A total of 190 households were visited, from which, a subset of 59 homes containing 205 children were considered priorities for intervention. Results were available for 78 children residing in 41 homes.

Intervention Strategy. The one-time intervention consisted of chemical stripping with caustic products, encapsulation (consisting of covering the toxic paint with coating material which prevents the dispersion of chips and particles into the home), replacement of antiquated elements and paint coatings of lead-based paints, and a final dust cleaning. Chemical stripping, using Peel Away™, was used on 52% of the items abated, a combination of stripping and encapsulation was used on 36% of the items abated, and a combination of encapsulation and replacement was used on 12% of the abated items. Families were relocated during the performance of the abatements.

Measurements Taken. For the 190 households visited, a score (0 to 5) was given to each household to assess the state of deterioration of the building. The score was determined as a function of the general condition of the building (structure and equipment), of its maintenance, of the cleaning of the floor, and the condition of the paint of the walls and woodwork. A similar score was used to determine the state of deterioration of the apartments. Paint samples were taken down to the substrate with a knife on the most degraded walls of the home and on surfaces most likely to contain lead-based paint. Dust samples were collected in 29 homes with a paper towel impregnated with alcohol by wiping the floor 1 meter from the wall, over an area of 30 cm by 30 cm. Dust sample measurements were taken at baseline, during the intervention, 1 to 2 months, 3 to 6 months, and 7 to 12 months post-intervention. Venous blood samples were taken at baseline and at least 2 times post-intervention.

Study Design. In this prospective study, 59 homes containing 205 children were selected for lead-based paint abatement. Main outcome measurements were paint lead content, pre-intervention dust-lead loading, post-intervention dust-lead loading, pre-intervention blood-lead levels and post-intervention blood-lead levels. Paint samples were collected in 147 of the 190 homes visited. Dust samples were collected in 29 homes and measurements were taken at baseline, during the intervention, 1 to 2 months, 3 to 6 months, and 7 to 12 months post-intervention. Blood samples were taken at baseline and 2 times post-intervention.

Study Results. The maximum lead content of paint was greater than 1.5 mg/g in 93% of the homes and 77% had greater than 10 mg/g lead content. The characteristics of the 59 homes selected for abatement did not differ significantly from the total number evaluated. Maximum lead content in paint for the 59 homes exceeded 1.5 mg/g in 58 homes and exceeded 10 mg/g in 52 of them.

Dust sample data was available for 24 of the 29 households in which they were collected. Characteristics of these 24 homes were compared to the other 35 homes for which dust sample data was unavailable (Table A.6-1). Initial conditions were slightly less severe in homes where dust samples were collected. Median floor dust-lead loadings measured 83.6 $\mu g/ft^2$ at pre-intervention and showed an increase of 697 $\mu g/ft^2$ during the intervention activities. However, post-intervention dust-lead loadings showed a median decrease of 33.9 $\mu g/ft^2$ at 1 to 2 months follow-up and 45.4 $\mu g/ft^2$ at 3 to 6 months follow-up. For 11 homes that had an initial dust-lead loading greater than 92.9 $\mu g/ft^2$, median decreases were 144 $\mu g/ft^2$ 1 to 2 months and 157 $\mu g/ft^2$ 3 to 6 months following intervention. By 6 to 28 months post-abatement, the maximum dust-lead loadings were less than 92.9 $\mu g/ft^2$ for 40 out of 45 households sampled.

Table A.6-1. Comparison of Housing Characteristics for Homes with Dust Samples Collected to Other Abated Homes

Characteristic	Homes with Dust Samples (N = 24)	Other Abated Homes (N = 35)	p-value	All Homes (N = 59)
Building Degradation[a] Score	1.7	2	0.03[b]	1.8
Apartment Degradation[a] Score	2.2	2.6	0.06[b]	2.4
Scraping Traces in Building (%)	62	74	0.33[c]	69
Scraping Traces in Apartment(%)	79	86	0.51[c]	83
Maximum Paint Lead Content (mg/g)[a]	45	28	0.21[b]	44
Number of Children < 6 yrs[a]	3	3	0.09[b]	3
Maximum PbB Pre-Intervention (µg/dL)[a]	52	60	0.88[b]	54
Monthly Rent (FF/ft^2)[a]	5	5.1	0.71[b]	5
Area per Person (ft^2)[a]	0.5	0.4	0.20[b]	0.4

[a] The median value is reported in the table.
[b] Mann-Whitney non-parametric test.
[c] Chi-squared test.

Pre- and post-intervention blood-lead levels were available for seventy eight of the 205 children residing in 41 of the 59 homes. Characteristics of these 41 homes were compared to the other 18 households for which no post-intervention blood data was available (Table A.6-2). Households where blood-lead concentrations were available for both pre- and post-intervention were significantly more deteriorated than for the other families. The maximum pre-intervention blood-lead level was also significantly higher in those homes. Maximum paint lead content was lower, however, lead concentrations of paint were already very high for both groups. Blood-lead levels increased for 4 of the 78 children post-intervention. These 4 children resided in 2 of the 41 homes. All other children's blood-lead concentrations decreased significantly post-intervention.

Table A.6-2. Comparison of Housing Characteristics for Homes with Both Pre- and Post-Intervention Blood-Lead Levels Reported to Other Abated Homes

Characteristic	Homes with Both Blood-Lead Levels (N = 41)	Other Abated Homes (N = 18)	p-value	All Homes (N = 59)
Building Degradation[a]	2	1.6	0.05[b]	1.8
Apartment Degradation[a]	2.6	2.2	0.09[b]	2.4
Scraping Traces in Building (%)	73	61	0.35[c]	69
Scraping Traces in Apartment(%)	88	72	0.14[c]	83
Maximum Paint Lead Content (mg/g)[a]	28	62	0.02[b]	44
Number of Children < 6 yrs[a]	3	3	0.87[b]	3
Maximum PbB Pre-Intervention (µg/dL)[a]	62	43.5	0.06[b]	54
Monthly Rent (FF/ft^2)[a]	5	5.3	0.29[b]	5
Area per Person (ft^2)[a]	0.4	0.37	0.40[b]	0.4

[a] The median value is reported in the table.
[b] Mann-Whitney non-parametric test.
[c] Chi-squared test.

A multiple linear regression model was conducted on the data collected for the 74 children whose blood-lead levels decreased post-intervention (Table A.6-3). The model regressed the natural logarithm of blood-lead levels on the following dependent variables: Time (weeks) after screening; Time (weeks) after intervention; Age (0 for < 3 years, 1 for   3 years); After Chelation Therapy (0 for no chelation performed, 1 for chelation performed); 15 < PbB < 45 (1 if 15 < PbB 45, 0 otherwise); PbB   45 (1 if PbB   45, 0 otherwise); and After Intervention (0 if pre-intervention, 1 if post-intervention). The 4 children whose blood-lead concentrations increased post-intervention were excluded from the regression analysis, presumably because the children were exposed to high levels of lead-contaminated dust during the intervention. Although families were relocated during the abatement, the two families of these 4 children may not have been relocated.

Table A.6-3. Multiple Linear Regression on Natural Logarithm of Blood-Lead Levels of Children Pre- and Post-Intervention[a,b]

Model Input Variable	Model Coefficient	p-value
Constant	5.348	< 0.0001
Age	0.054	0.15
After Chelation Therapy	0.225	< 0.0001
15 < PbB < 45	0.367	< 0.003
PbB 45	0.884	< 0.0001
Time (weeks) After Screening	-0.003	< 0.0001
After Intervention	-0.237	0.0001
Time (weeks) After Intervention	0.001	0.25

[a] Analysis excludes 4 children whose blood-lead levels increased post-intervention.
[b] R^2 = 0.58.

Conclusions (including caveats). These results suggest that the intervention was beneficial to severely lead poisoned children exposed to severe pre-intervention conditions. The one time interventions seemed to have had a lasting effect in reducing interior dust-lead levels. As noted by the substantial increase in dust-lead loadings during the abatements, families should be relocated during the rehabilitation process. As no specific guidelines were set for the abatement process itself, comparisons on a house to house basis may not be feasible. The magnitude of the reduction in blood-lead levels may be confounded with seasonal variation as sampling occurred at various time intervals. Furthermore, the decline is confounded with chelation therapy, which was provided to some of the more severe lead poisoned children.

A.7. Baltimore Follow-up Paint Abatement Study

Reference. Maryland Department of the Environment (1995) Final Report on Grant H64/CCH 30 7067-03 to U.S. Department of health and Human Services, Public Health Service, Centers for Disease control and Prevention. March 1995.

Pertinent Study Objectives. This study sought to evaluate the effectiveness of alternative lead-based paint procedures on long-term reduction in household dust-lead levels.

Sampled Population. Environmental inspection records of 186 households from the Baltimore area were reviewed. These homes, identified by the Baltimore City Lead Poisoning Prevention Program, had previously been abated under a pilot program. Eighty-nine homes, which underwent abatements between January 1, 1991 and June 30, 1992 and had at least one clearance dust lead measurement, were selected from the review. Of the 89 homes, 75 were abated using alternative methods, 13 used traditional methods, and for one home the method was unknown. Due to the small number of traditional abatements, this study was limited to households with alternative abatements. A final sample size of 72 homes abated using alternative methods, for which clearance tests were available, was used.

Intervention Strategy. Alternative abatement 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.

Measurements Taken. Wipe dust-lead loading samples were taken from floors, window sills, and window wells in rooms where the child spent time.

Study Design. This study evaluated 72 homes that were abated using alternative methods between January 1, 1991, and June 30, 1992, for which clearance tests were available. The homes were abated under another program. Outcome measurements were wipe dust-lead loading for floors, window sills, and window wells. Of the 72 homes, 69 had at least one floor clearance sample, 67 had at least one window sill clearance sample, and 57 had at least one window well clearance sample. Follow-up samples were collected in this study. Three time intervals were used to group the follow-up dust measurements. These intervals were 5-7 months, 10-14 months, and 14-24 months, which were labeled by their midpoints as 6, 12, and 19 months, respectively.

Study Results. Table A.7-1 shows the geometric mean and 95% confidence interval on the mean dust-lead loading results taken at clearance, for all homes and for homes with samples at both clearance and the specified follow-up time interval. For example, 29 homes had both clearance and 6-month follow-up floor samples taken, with geometric means of 19 µg/ft^2 at clearance reducing to 15 µg/ft^2 by the 6-month follow-up. Geometric mean floor dust-lead loadings seemed to remain fairly constant over the course of this study, whereas window sill and window well dust-lead loadings showed recontamination fairly quickly. Clearance levels for floors, window sills, and window wells were set at 200 µg/ft^2, 500 µg/ft^2, and 800 µg/ft^2, respectively. By 19 months post-intervention, only 5% of the homes were above clearance for floors, while 42% and 47% of the homes were above clearance levels for window sills and window wells, respectively.

Table A.7-1. Wipe Dust-Lead Loading (µg/ft^2) by Specified Time Interval and Surface Type

Time Interval		Floors		Window Sills		Window Wells	
		N	Geo. Mean (95% CI)	N	Geo. Mean (95% CI)	N	Geo. Mean (95% CI)
Clearance		69	24 (19,29)	67	34 (27,44)	57	64 (48,86)
6 Months	Clearance	29	19 (14,26)	27	31 (21,47)	23	65 (43,100)
	Follow Up		15 (11,20)		42 (27,66)		123 (73,204)
12 Months	Clearance	27	26 (17,38)	26	31 (20,47)	21	73 (45,115)
	Follow Up		14 (11,19)		26 (30,72)		180 (90,361)
19 Months	Clearance	22	16 (10,24)	19	31 (13,32)	15	35 (24,50)
	Follow Up		23 (14,38)		79 (39,158)		347 (150,804)

Conclusions (including caveats). The results for the alternative abatement methods indicate that dust-lead loadings on floors can be kept fairly low over long-term time periods. Floor surfaces showed little evidence of recontamination. However, reaccumulation of lead-containing dust occurred in window sills and window wells at each time interval examined. Reaccumulation was greatest for window wells with 17%, 43%, and 47% of homes at or above clearance standards by the 6, 12, and 19 month time intervals, respectively. Although the homes were reoccupied, blood-lead concentrations of resident children were not collected since these children were not present in the home prior to abatement.

A.8. <u>Leadville/Lake County Educational Intervention Study</u>

Reference. Lake County Department of Health and University of Cincinnati, "The Leadville/Lake County Environmental Health Lead Study — Report of the 1992 Follow-up Lead Screening." July 12, 1993.

Pertinent Study Objectives. This study's relevant objectives were to compare the average community blood-lead concentrations (PbB) with those determined in 1991 and evaluate the post-intervention PbB levels of children whose pre-intervention PbB level was elevated, or who lived in residences with unusually high concentrations of lead or arsenic in the surrounding soil.

Sampled Population. The sampled population consisted of 160 individuals, of which, 127 were children. One hundred thirteen of the 127 children were less than 72 months of age.

Intervention Strategy. Only educational efforts targeting residential lead exposure were studied. If a child's blood-lead concentration was found to be 10 µg/dL or higher, parents were informed on methods to reduce their child's lead intake.

Measurements Taken. Venous blood samples were taken during the two fall screening clinics conducted one year apart.

Study Design. This screening study compared community blood-lead concentrations in 1992 with those determined in 1991 and evaluated the effect of educational intervention on blood-lead levels of children whose pre-intervention level was elevated, or who lived in residences with unusually high concentrations of lead or arsenic in the surrounding soil. A 20% random sample of the families who had blood lead measurements during the 1991 fall screening clinic were targeted for the 1992 screening. A total of 66 children were tested in both 1991 and 1992. If a child's blood-lead concentration was 10 µg/dL or higher, parents received instruction on methods to reduce their child's lead intake. Venous blood samples were taken during the two fall screening clinics conducted one year apart. The main outcome measurement was blood-lead concentration.

Study Results. Of the children whose blood-lead concentration was measured at both screenings, the geometric mean blood-lead concentration declined from 5.02 µg/dL to 4.53 µg/dL during the year. Twenty-six of these targeted children had not moved during the year. Their geometric mean blood-lead levels declined by 25%, from 5.83 µg/dL to 4.38 µg/dL. Eight children were identified as having elevated (>10 µg/dL) blood-lead levels in 1991. These children showed an average decline in PbB of 19% from a geometric mean of 11.4 µg/dL to 9.3 µg/dL. Two of these children had reductions in blood-lead concentrations of 49% and 57%.

Conclusions (including caveats). For children in the Leadville/Lake county areas, blood-lead concentrations declined by an average of approximately 9 percent over the one year period. In comparison, eight children benefitting from educational intervention showed a 19% decline on average. These 8 children were targeted since they exhibited elevated blood-lead concentrations at the initial survey, so the decline may be due to other non-interventional factors such as regression to the mean, or merely age-related variation. The absence of a comparable control population makes assessment of these issues difficult.

A.9. Trail Dust Intervention Study

Reference. Hilts, S.R., Hertzman, C., Marion, S.A. (1995) "A Controlled Trial of the Effect of HEPA Vacuuming on Childhood Lead Exposure." *Canadian Journal of Public Health*. 86(5):345-350.

Hilts, S.R. (1996) "A Co-operative Approach to Risk Management in an Active Lead/Zinc Smelter Community." *Environmental Geochemistry and Health.* 18(1):17-24.

Hilts, S.R., Bock, S.E., Oke, T.L., Yates, C.L., Copes, R.A. (1998) "Effect of Interventions on Children's Blood Lead Levels." *Environmental Health Perspectives*. 106(2):79-83. February.

Pertinent Study Objectives. A variety of intervention strategies have been implemented in Trail, British Columbia, with the goal of reducing children's blood-lead levels in the presence of ongoing emissions from a lead and zinc smelting facility. Intervention strategies have targeted lead-containing house dust. Of particular interest is a study that sought to determine the effectiveness of repeated vacuuming using high efficiency particle accumulator (HEPA) vacuums in reducing both household dust-lead loading (PbD) and children's blood-lead concentrations (PbB) (Hilts et al., 1995). In addition, programs of education and case management, community greening and dust control, and residential bare soil reduction have been implemented (Hilts, 1996).

Sampled Population. HEPA Vacuum Study: The sample population consisted of 207 households in higher risk areas of Trail, British Columbia, with children under six years of age who had participated in a 1992 blood lead screening. Of the 207 families, 122 agreed to participate in the study. The children were randomly assigned to a treatment and a control group (61 children in each group). Fifty-five treatment group children and 56 control group children completed the study. A follow-up study was conducted in 17 homes located in high risk neighborhoods (Hilts, 1996).

Other interventions: Community education, greening, and dust control programs were designed to benefit all children in Trail. Education and case management services were available to children with elevated blood-lead levels (PbB>15, or PbB>10 for children under 1 year old) who are identified in annual fall screening clinics.

Intervention Strategy. HEPA Vacuum Study: Dust intervention for the treatment group consisted of HEPA vacuuming of accessible finished floors once every six weeks over a period of ten months, from November 1992 through August 1993. During the first vacuuming cycle, carpeted floors were vacuumed at a rate of 22 seconds per square meter (s/m^2), but was thereafter slowed to 32 s/m^2. Non-carpeted floors were vacuumed at an average rate of 4 s/m^2. The control group did not receive these vacuumings. Families in both groups, however, received educational materials and recommendations to reduce childhood lead body burden, and were advised to continue their normal cleaning habits throughout the course of the study. Families in the follow-up study received HEPA vacuuming, wet-mopping, and wet-wiping biweekly during the summer months.

Other interventions: Soil interventions were not performed, because recontamination was almost inevitable from the 300 kg of lead per day in smelter stack emissions. However, seeding and planting of public areas with high lead levels was implemented by a civic group. In addition, a residential ground cover program implemented in 1993 provided a 50% rebate on cost of materials to householders who covered bare soil with turf, landscape fabric and mulch, shrubs, concrete, or gravel. Community dust levels were reduced by spraying magnesium chloride dust suppressant on unpaved alleys and parking areas.

Education and case management activities began in 1991 and have evolved over time. Community education efforts focused on contacts with elementary school or daycare administrators, instructors, and students. Individual education and case management activities include blood-lead monitoring and in-home educational visits. Since 1994, ground cover materials or cleaning supplies, equipment, and services have been provided, as well. Cleaning services include biweekly cleaning during summer and monthly cleaning the rest of the year, using the methods of the follow-up study.

Measurements Taken. HEPA Vacuum Study: Hand wipe and floor dust-lead samples were collected three times during the study for both treatment and control homes. Floor dust samples were collected from three carpeted areas where the child spent time, using the ‘microvac’ method. In treatment homes, floor dust-lead levels were collected immediately before and after HEPA vacuuming. In addition, the contents of the vacuum bag were weighed and analyzed for lead content by inductively coupled plasma atomic emission spectrometry (ICP-AES). Baseline and post-intervention venous blood samples were collected at fall screening clinics approximately one year apart. Blood samples were analyzed by atomic absorption spectrometry. Additionally, a 19-part self report survey was administered at the time of the post-intervention blood lead screening. This included questions on household practices and lead exposure assessment.

Other interventions: Soil-lead measurements were taken in 1989 and 1992 to assess directly the effectiveness of community greening, dust-control, and ground cover subsidy interventions. Community blood-lead screening clinics were held in the fall of 1989, 1991, 1992, 1993, 1994, 1995, and 1996. Participation in these clinics has been high, with 75-80% of children participating and 85-90% of eligible children participating in follow-up clinics for children with elevated blood-lead levels.

Study Design. HEPA Vacuum Study: The study was designed to assess benefit of repeated house vacuuming using HEPA vacuum cleaners. The 55 treatment homes received thorough vacuuming of finished accessible floors areas once every 6 weeks for 10 months, while 56 control homes did not. A follow-up study was conducted in 17 homes located in high-risk neighborhoods. Families in the follow-up study received HEPA vacuuming, wet-mopping, and wet-wiping once every 2 weeks over the summer months. There was no random assignment to a control group in the follow-up study, although 10 children living in the same neighborhoods were available for comparison.

Other interventions: The other interventions were available or benefitted all members of the community. Soil-lead measurements were sampled in 1989 and 1992 to assess the effectiveness of the other interventions.

Primary outcome measurements for both studies were blood-lead concentration, dust loading and dust-lead loading.

Study Results. HEPA Vacuum Study: A marginally significant decrease in blood-lead concentrations was observed during the study in the treatment group, with a lesser decline in the control group (Table A.9-1). However, the difference in pre- and post-intervention changes in blood-lead concentrations between the treatment and control group was not significant (p=0.85).

Table A.9-1. HEPA Vacuum Study: Blood-Lead Concentration (µg/dL) by Study Group and Time

Study Group	Sample Size	Pre-Intervention Geometric Mean	Post-Intervention Geometric Mean	p-value for Change
Treatment	55	11.9	11	0.06
Control	56	11.3	10.7	0.23

Floor dust-lead loading was measured prior to and immediately after vacuuming in treatment households. For treatment homes, vacuuming showed an immediate reduction in carpet surface dust-lead loading and total dust loading by an average of about 40 percent. There was no significant reduction in carpet dust-lead concentration (p=0.41). Results for the first vacuuming cycle are shown in Table A.9-2. During the first vacuuming cycle carpet dust loading, carpet dust-lead loading, and carpet dust-lead concentration were reduced by 34, 39, and 8 percent, respectively, as compared to their measures prior to vacuuming. Carpet dust loading, carpet dust-lead loading, and carpet dust-lead concentration were reduced by 34, 35, and 3 percent during vacuuming cycle 4, and 46, 47, and 0 percent, respectively, for the seventh cycle. In addition, hand lead and dust-lead levels were measured three times during the course of the study for both the control and treatment groups. These measurements were conducted during the first, fourth, and seventh vacuumings.

Table A.9-2. HEPA Vacuum Study: Change in Carpet Surface Dust as an Immediate Result of Cycle One HEPA Vacuuming

Parameter	Sample Size	Range	Pre-intervention Geometric Mean	Percent Change in Parameter
Carpet Dust Loading (µg/ft²)	56	1951-1205138	52862	-34
Carpet Dust-Lead Loading (µg/ft²)	56	< 2.51-694	52	-39
Carpet Dust-Lead Concentration (ppm)	56	< 0.027-12931	971	-8

Geometric mean hand-wipe lead loading decreased significantly for the control group, while a marginally significant increase was observed in the treatment group during the study. Carpet dust loading increased for the control group and decreased for the treatment group. Carpet dust-lead loading decreased for both the control and treatment groups (Table A.9-3).

Table A.9-3. HEPA Vacuum Study: Geometric Mean Dust-Lead Loadings Prior to Cleaning by Vacuuming Cycle and Treatment Group

Study Group	Parameter	Vacuuming Cycle			p-value for Change (Pre-Post)
		Pre-Intervention	Mid-Project	Post-Intervention	
Control	Hand-Wipe Lead Loading (µg)	10	9	6	0.005
	Carpet Dust Loading (µg/ft²)	33724	44315	41156	0.25
	Carpet Dust-Lead Loading (µg/ft²)	25.1	25.1	21.4	0.21
Treatment	Hand-Wipe Lead Loading (µg)	11	13	15	0.08
	Carpet Dust Loading (µg/ft²)	52862	38648	30193	0.01
	Carpet Dust-Lead Loading (µg/ft²)	52	34.4	33.4	0.01

Eighteen households were sampled weekly for evidence of recontamination for a period of six weeks after the final vacuuming cycle in August 1993. In these 18 homes, carpet surface dust-lead loadings had declined by approximately 50 percent immediately following the final vacuuming. However, recontamination occurred within 2 ½ to 3 weeks, on average. In addition to the dust recontamination sampling, a self-report survey questionnaire was completed by 103 of the study participants at the post-intervention blood lead screening. Children living in homes where people removed their shoes at the door tended to have lower blood-lead levels and floor dust-lead loading tended to be lower also. Children who had pets tended to have higher blood-lead levels and higher floor dust-lead loadings.

Although HEPA vacuuming every 6 weeks did not have a significant impact on blood-lead levels, there was some evidence to suggest that more frequent vacuuming might be beneficial. The follow-up study, which provided biweekly cleaning in 17 homes during the summer months, was effective in preventing a seasonal rise in dust-lead loadings on carpets, but less effective in preventing a rise in blood-lead concentrations. The average carpet dust-lead loading stayed the same in treated homes, but nearly doubled in 14 comparison homes during the study period (Table A.9-4). The average blood-lead concentration rose by 2.9 g/dL in the treatment group and by 4.2 g/dL in 10 comparison children between April and September 1993. Comparison children and homes were in the same neighborhoods as the treatment homes, but the follow-up study did not randomly assign homes to treatment and control groups.

Table A.9-4. Follow-up HEPA Vacuum Study: Change in Carpet Dust-Lead Loadings by Study Group and Time

Study Group	Sample Size	Pre-Intervention Average	Post-Intervention Average	p-value for Change
Treatment	17	43.7	39	0.6
Comparison	14	48.3	83.6	0.01

<u>Other interventions</u>: Geometric mean soil-lead levels did not change significantly between 1989 and 1992 (GM=725, n=119 and GM =713, n=213, respectively). Therefore, the 14% decline in blood-lead concentrations from 1991 to 1992 and the additional 6% decline from 1992 to 1993 may be attributed primarily to the education efforts. The ground cover subsidy program was open to all families who had participated in the 1992 Fall blood clinic who also had bare soil in their yards. The participation rate was 23%, with 44 families completing projects. A follow-up assessment in 1994 found that the ground cover projects were being maintained adequately, however, 12 of the 44 properties had additional bare soil.

Conclusions (including caveats). The lead loading of house dust may be reduced temporarily by thorough HEPA vacuuming once every six weeks. In fact, carpet dust-lead loading was reduced by approximately 40 percent immediately following the vacuuming. However, with the on-going contamination stemming from the operational smelter, these levels return to 'normal' within a few weeks. Vacuuming every six weeks, even accompanied by education, had no effect on children's blood-lead concentrations. The follow-up study with biweekly cleaning appeared to be successful in preventing some of the summer rise in blood-lead concentrations, although the results were not conclusive. The ground cover subsidy program had a 23% participation rate, with 44 families completing projects and maintaining them for at least one year.

In 1991, a 14% decline in the average blood-lead concentration of Trail children aged 6 to 72 months was attributed primarily to the first year of community education and individual case management efforts. However, declines in subsequent years for children whose families received case management intervention for the first time were not as notable as that found in 1991.

A.10. New Jersey's Children's Lead Exposure and Reduction Dust Intervention Study

Reference. Rhoads, G.G., Ettinger, A.S., Weisel, C.P., Buckley, T.J., Goldman, K.D., Adgate, J., Lioy, P.J., (1999) "The Effect of Dust Control on Blood Lead in Toddlers: A Randomized Trial." *Pediatrics*. 103(3):551-555.

Lioy, P.J., Yiin, L., Adgate, J.,Weisel, C.P., Rhoads, G.G., (1998), "The Effectiveness of a Home Cleaning Intervention Strategy in Reducing Potential Dust and Lead Exposures." *Journal of Exposure Analysis and Environmental Epidemiology*. 8(1):17-35..

Rhoads, G.G., Ettinger, A.S., Goldman, K.D., Weisel, C.P., Buckley, T.J., and Lioy, P.J. (1996), "The Effect of a Dust Lead Control Program Combined with Health Education on Blood Lead in Toddler: A Randomized Study." Presented at the American Public Health Association Conference, New York City, New York. November,1996 (Submitted *NJM*, 1997).

Buckley, T.J., (1996) "Significant Findings from the *Children's Lead Exposure and Reduction Study* (CLEARS)." U.S. EPA Memorandum. May 2, 1996.

Buckley, T.J., (1996) "Selection Criteria for CLEARS Relating to Blood-Pb." Personal Communication to Brad Schultz. March 22, 1996.

Pertinent Study Objectives. This study sought to demonstrate the effectiveness of a combined dust control and educational intervention strategy for reducing blood lead levels and potential dust and lead exposures in children with low to moderate blood-lead levels.

Sampled Population. The study targeted children between 6 months and 3 years of age residing in Jersey City, NJ who were at risk for elevated blood-lead concentrations. Subjects were eligible for participation if they met at least one of the following criteria: (1) having a sibling with a previously reported blood-lead concentration greater than 10 µg/dL, (2) high lead contamination in the home, or (3) a measured blood-lead concentration between 8 and 20 µg/dL. Out of 211 families visited, 113 were deemed eligible and enrolled in the study. They were assigned at random to the Lead Group (LG), which was offered biweekly assistance with home dust control and a series of educational sessions about lead, or the (control) Accident Group (AG), which was offered only education and home safety items related to accident prevention. The two groups were followed for 1 year.

Intervention Strategy. The lead hazard intervention consisted of biweekly assistance with home dust control (which included wet mopping of floors, damp-sponging of walls and horizontal surfaces, and vacuuming with a high-efficiency particle accumulating (HEPA) vacuum) and a series of educational sessions about lead. The cleaning teams provided the education during the course of their visits and mainly focused on teaching the caretakers how to clean the home.

Measurements Taken. Dust wipe floor samples were collected from uncarpeted locations in the kitchen and one other room frequented by the enrolled child. Additional samples were collected from interior window sills when time allowed, and if carpets were present, vacuum samples were collected from those locations where the child was likely to play. A baseline venous blood specimen was also obtained from the enrolled child. Dust samples were collected once during the course of the intervention, and blood and dust measurements were taken once again after one year (when the intervention was completed).

An "LWW" sampler was used for collection of dust wipe samples. This method was chosen because it allows separate quantification of total dust and lead loading. In side-by-side comparisons, the LWW sampler yielded lower lead loading estimates than the wipe sampling method recommended by HVD (Freeman et al., 1996).

Study Design. In this study, 56 families were assigned to the lead group (LG) and 57 to the accident group (AG). The two groups were followed for 1 year. A combined dust control and educational intervention method was used in this project. The LG families received 1 to 5 (median 3) one hour educational sessions and 0 to 42 (median 17) cleaning visits. The two groups were very similar with respect to age, number of children, education, and proportion speaking English. The mothers also had a similar baseline knowledge of lead poisoning. Main outcome measurements were dust-lead loading and blood-lead concentration.

Study Results. The geometric means of dust and dust-lead loadings are shown in Table A.10-1 for all homes in each group where samples were obtained. Baseline levels were comparable among the LG and AG. By the one year follow-up, the dust and dust-lead levels were lower in the LG group for floor, sill and vacuum samples. The decrease in floor dust and dust-lead loadings was not very large, but the decreases in loadings on sills and carpets were 50% or larger for the LG. The changes in the AG dust and dust-lead loadings were smaller and inconsistent. For reasons that are not clear, there was a substantial drop in the lead loading of the vacuum samples from the AG. This narrowed the difference between the LG and AG. Thus, there was not a significant difference in carpet lead loading between these two groups. However, there were significant differences in the dust loadings for sills and carpets between the two groups, and there was a significant difference in the sill lead loading between the LG and the AG.

Table A.10-1. Household Dust Results and Analysis

Type of Dust Measurement	Time Sampled	Sample Type	Lead Group		Accident Group	
			N	Geometric Mean (µg/ft²)	N	Geometric Mean (µg/ft²)
Dust Loading	Initial Visit	Floor Wipe	42	38547	42	39391
		Sill Wipe	39	70327	40	77016
		Vacuum	27	784095	28	683017
	Final Visit	Floor Wipe	40	35117	45	36696
		Sill Wipe	36	35303	40	53698*
		Vacuum	22	282423	27	736994**
Dust-Lead Loading	Initial Visit	Floor Wipe	42	22	42	26
		Sill Wipe	39	75	40	61
		Vacuum	27	469	28	466
	Final Visit	Floor Wipe	40	15	45	19
		Sill Wipe	36	24	40	48**
		Vacuum	22	150	27	214

Significance of differences between intervention and control groups shown as: * $p < 0.1$; ** $p < 0.05$

The paper by Lioy, et al. presented a more detailed analysis of the dust samples that were obtained as part of the NJ CLEARS. An analysis of the vacuum and wipe sample dust and dust-lead loadings from the LG and AG groups was performed for a subset of homes where sampling data were available for all surfaces for all three visits. This analysis indicated that a thorough cleaning program will reduce the geometric mean of the dust and lead loading and found that 68%, 75%, and 81% of the LG homes had a reduction in lead loading on the kitchen floors, bedroom floors, and window sills, respectively. Seventy-eight percent of the vacuum samples from LG homes had a reduction in lead loading, while the sampling results for the AG homes did not show any consistent trends over time for any surface type.

As shown in Table A.10-2, baseline blood levels were slightly higher in the LG, but the difference between this group and the AG was not significant. After 1 year of intervention the blood-lead concentrations in the LG group had decreased on average from 12.4 µg/dL to 10.3 µg/dL (a 17% decline). In contrast, blood-lead concentrations in the AG group increased from 11.6 to 11.7 µg/dL on average during that time (0.9% increase). The difference in the change in blood-lead concentrations between LG and AG children was statistically significant ($p<0.05$). Also, the reduction in blood-lead levels among the LG children was greater the more times their residence was cleaned. There was essentially no change in blood lead levels (-0.2 µg/dL) for the 11 children whose homes were cleaned less than 10 times, as opposed to a 34% drop (-3.9 µg/dL) in blood lead for the 16 children whose homes were cleaned 20 or more times.

Table A.10-2. Initial Blood-Lead Concentration and Change in Blood-Lead Concentration at One Year Follow-up

Treatment Group	Initial Blood-Lead Concentration (μg/dL)			Change in Blood-Lead Concentration at One Year Follow-up (μg/dL)	
	N	Mean	SD	Mean	SD
Lead	46	12.4	5.7	-2.1	5.7
Accident	53	11.6	6.2	0.1	6.3

Conclusions (including caveats). It appears that the combination of biweekly dust control and a series of lead-education sessions was effective in reducing blood-lead levels and the dust and lead loadings on surfaces in the homes of this population of children with moderately elevated blood lead. The effect of seasonal variation was minimized by taking blood lead measurements one year apart. However, the effect of the intervention cannot be separated from the effect of changing mouthing behavior in young children over the course of a year. Since a similar decline was not observed in the control group, the decline in blood lead may reasonably be attributed to the intervention.

A.11. Boston Interim Dust Intervention Study

Reference. Aschengrau, A., Hardy, S., Mackey, P., and Pultinas, D. (1998) "The Impact of Low Technology Lead Hazard Reduction Activities among Children with Mildly Elevated Blood Lead Levels." *Environmental Research*. 79:41-50.

Mackey, P., Aschengrau, A., Balasko, C., Pultinas, D., Hardy, S. (1996) "Blood Lead Levels Following Environmental Intervention Study", Final Report on Grant H64/CCH 108235-03 to U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention.

Pertinent Study Objectives. This study sought to determine the effectiveness of low-technology lead hazard reduction activities targeting paint and household dust in reducing modestly elevated blood-lead concentrations in children awaiting permanent deleading of household paint.

Sampled Population. Children residing in the city of Boston who were less than four years of age were selected for possible enrollment, each satisfying the following criteria:

- venous blood-lead level between 11 and 24 µg/dL, with no history of lead poisoning,
- lived in home for at least 3 months with no definite plans to move within the next 3 months,
- lived in home that had not been previously deleaded, or received lead hazard reduction activities, and that had lead-based paint on at least 2 window sills and/or window wells, and
- the parents spoke English, Spanish, or Cape Verdean creole.

A total of 402 children screened for lead from May 1993 to April 1995 met the eligibility criteria. Sixty-three of these children were enrolled. Of the 339 not enrolled, 163 families were unable to be contacted, 64 were unable to communicate effectively because of language barriers, and 112 families declined to participate. Twenty-two of the 63 children were assigned to the 'automatic intervention' group, because of severe household lead hazards. Severe hazards were characterized as paint chips on any floors, severe amounts of loose dust or paint chips in any window well, or holes larger than one inch wide in walls containing lead-based paint. The remaining 41 children were randomly assigned to two groups, 22 to the 'randomized intervention' group and 19 to the 'randomized comparison' group. Thirty-two of the 63 children originally enrolled were included in the blood lead analysis and others were excluded because no follow-up blood samples were taken or their homes received non-study environmental interventions. For final analysis, the automatic intervention, randomized intervention, and randomized comparison groups contained 8, 11, and 13 children, respectively.

Intervention Strategy. The one-time intervention, received by both the randomized and automatic intervention groups, consisted of HEPA vacuuming all window well, window sill, and floor surfaces; washing window well and window sill surfaces with a tri-sodium phosphate (TSP) and water solution; repairing holes in walls; and re-painting window well and window sill surfaces to seal chipping or peeling paint. The study intervention groups also received outreach and educational information including a demonstration of effective housekeeping techniques and monthly reminders with instructions to wash hard surface floors, window sills and wells with a TSP and water solution at least twice a week. The randomized comparison group received only the outreach visit to visually assess the home for lead hazards and to educate the family about the causes and prevention of lead poisoning. They were also provided with cleaning instructions and a free sample of TSP cleaning solution.

Measurements Taken. Dust sample measurements were taken at baseline and 6 months post-intervention for all study groups. Measurements were also taken at one month post-intervention for the two intervention groups, but the results were not reported. Dust samples were taken from floors, window sills, and window wells. Soil, water, and paint samples were taken at baseline. Dust, soil, and water samples were analyzed using atomic absorption spectrophotometry (AAS). Venous samples were obtained to determine blood-lead levels at baseline and an average of six months after intervention. Additionally, trained staff members conducted standardized interviews at enrollment to obtain demographic characteristics, and at a 6-month post-intervention visit to assess compliance with housekeeping instructions.

Study Design. The purpose of the environmental intervention was to significantly reduce children's exposure to household lead hazards by first removing lead-contaminated dust and loose paint chips from the window and floor areas and second instructing care givers to maintain clean window and floor surfaces over the follow-up period. A total of 402 screened for lead from May 1993 to April 1995 met the eligibility criteria. Sixty-three of these children were enrolled. Of the 339 not enrolled, 163 families were unable to be contacted, 64 were unable to communicate effectively because of language barriers, and 112 families declined to participate. Twenty-two of the 63 children were assigned to the 'automatic intervention' group, because of severe household lead hazards. Severe hazards were characterized as paint chips on any floors, severe amounts of loose dust or paint chips in any window well, or holes larger than one inch wide in walls containing lead-based paint. The remaining 41 children were randomly assigned to two groups, 22 to the 'randomized intervention' group and 19 to the 'randomized comparison' group. Thirty-two of the 63 children originally enrolled were included in the blood lead analysis and others were excluded because no follow-up blood samples were taken or their homes received non-study environmental interventions. For final analysis, the automatic intervention, randomized intervention, and randomized comparison groups contained 8, 11, and 13 children, respectively. Main outcome measurements were blood-lead concentration, dust-lead loading, soil-lead concentration and water-lead level.

Study Results. Mean blood-lead levels declined in all three groups 6 months after intervention (Table A.11-1). Mean blood-lead concentrations for children in the automatic intervention group declined by 48% at 6 months post-intervention, and declined by 35% and 36% for the randomized intervention and randomized comparison groups, respectively. Mean blood-lead levels decreased 0.3 µg/dL more in the randomized intervention group and 2.5 µg/dL more in the automatic intervention group as compared to the randomized comparison group.

Table A.11-1. Blood-Lead Concentration (µg/dL) by Study Group and Time

Study Group	Sample Size	Pre-Intervention Geometric Mean	Post-Intervention Geometric Mean	Percent Decrease (%)
Automatic Intervention	8	17.5	9.1	48
Randomized Intervention	11	17.6	11.5	35
Randomized Comparison	13	16.3	10.4	36

Table A.11-2 presents environmental dust-lead loadings for floors, window sills, and window wells. At the 6 month post-intervention measure, geometric mean floor dust-lead loadings had decreased slightly for both intervention groups and increased in the comparison group. Geometric mean window sill dust-lead loadings decreased in all three groups, and geometric mean window well dust-lead loadings decreased for both intervention groups, but remained the same for the comparison group. None of the changes in dust-lead loadings were statistically significant. Baseline soil-lead concentrations and water-lead levels for each group are reported in Table A.11-3.

Table A.11-2. Environmental-Lead Levels by Study Group and Time

Parameter	Study Group	Sample Size	Pre-Intervention Geometric Mean	Post-Intervention Geometric Mean
Floor Dust-Lead Loading (µg/ft²)	Automatic Intervention	10	21.5	16.1
	Randomized Intervention	9	23.8	20.5
	Randomized Comparison	13	15.8	16.4
Window Sill Dust-Lead Loading (µg/ft²)	Automatic Intervention	10	344	108
	Randomized Intervention	9	106	61.6
	Randomized Comparison	13	85.6	53
Window Well Dust-Lead Loading (µg/ft²)	Automatic Intervention	10	8955	2644
	Randomized Intervention	9	1119	561
	Randomized Comparison	8	1495	1510

Table A.11-3. Baseline Environmental-Lead Levels by Study Group

Parameter	Randomized Intervention Group (N = 11)	Automatic Intervention Group (N = 8)	Randomized Comparison Group (N = 13)
Soil-Lead Concentration (ppm)	2112	2278	2465
Water-Lead Level (µg/L)	6.3	4.6	7.7

Conclusions (including caveats). These results suggest that intervention was beneficial to children exposed to severe pre-intervention conditions, but did not have as significant an impact on children with less severe exposure conditions (randomized intervention and comparison groups exhibited roughly the same declines). The one time interventions seemed to have had a small impact on floor dust lead, an intermediate impact on window sill dust lead, and a large effect on window well dust lead. The blood and dust changes should be interpreted cautiously because the sample size was small and none of the results were statistically significant. The magnitude of the reduction in blood-lead levels may be confounded with seasonal variation as sampling occurred at approximately 6 month time intervals.

A.12. <u>Rochester Educational Intervention Study</u>

References. Lanphear, B.P., Winter, N.L., Apetz, L.J., Eberly, S., Weitzman M. (1995) "A Randomized Trial of the Effect of Dust Control on Children's Blood Lead Levels." Report on Grant NYLPR002-94 submitted to U.S. Department of Housing and Urban Development, Washington, D.C. and National Center for Lead-Safe Housing, Columbia, MD.

Lanphear, B.P., Winter, N.L., Weitzman M. (1996) "A Randomized Trial of the Effect of Dust Control on Children's Blood Lead Levels." *Pediatrics.* 98(1):35.

Pertinent Study Objectives. This study sought to determine the effectiveness of simple dust control as a means of lowering blood-lead concentrations in children.

Sampled Population. The study population consisted of 104 urban children, ages 12 to 31 months at enrollment, with low to moderate blood-lead levels. This population was identified and recruited from the original 205 children that participated in the Rochester, NY, Lead-In-Dust Study.

Intervention Strategy. A trained interviewer visited families assigned to the Intervention Group at the time of baseline sampling. The importance of dust control as a means of reducing lead exposure was emphasized and cleaning supplies were provided. These included paper towels, spray bottles and Ledisolv, a detergent developed specifically for lead contaminated house dust. Families were instructed to clean the entire house once every three months, interior window sills, window wells and floors near windows once every month, and carpets once a week with a vacuum cleaner, if available. For families assigned to the Control Group, only a brochure was provided containing information about lead poisoning and its prevention.

Measurements Taken. Blood lead measurements were collected via venous blood samples. Household dust lead measurements were collected (using a K-mart brand of baby wipes) from entryway floors and the kitchen, as well as from the floors, interior window sills and window wells of the child's principal play area.

Study Design. One hundred four children, 12 to 31 months of age at baseline were followed for seven months in this study. They were randomly assigned to either the intervention group or the control group. Families of children in the intervention group received cleaning supplies, information about cleaning areas that are often contaminated with lead, and a cleaning demonstration. Families in the control group received only a brochure about lead poisoning prevention. Baseline measurements of lead in blood, house dust, soil, water, and paint were taken from both groups. Seven months after enrollment, a second blood lead assay was obtained, and lead levels in household dust were measured. The main outcome measures were change in blood lead levels and dust lead levels by study group.

Study Results. Baseline and follow-up blood-lead levels are summarized in Table A.12-1 and A.12-2. Differences between baseline and follow-up blood-lead concentrations and dust-lead levels in the Intervention and Control Groups were tested using (non-parametric) Wilcoxon tests with two-tailed p-values. The median change for the Intervention Group was -0.05 µg/dL compared with -0.6 µg/dL for the Control group, which was not a statistically significant difference (p=0.95). The median change in blood-lead concentration for 28 children whose families used Ledisolv as instructed (at least once each month) and for the 65 children whose families did not use Ledisolv as instructed or were assigned to the control group were also -0.05 µg/dL and -0.6 µg/dL, respectively. Again the difference was not statistically significant (p=0.74). No statistical comparisons of blood-lead levels were made among the subset of 80 children whose families did not move.

Table A.12-1. Percentage of Children With Blood-Lead Concentrations Exceeding Various Blood Lead Levels at Baseline and Follow-Up, by Study Group

	Intervention Group		Control Group	
	Baseline	Follow-up	Baseline	Follow-up
No. (%) > 10 µg/dL	13 (25%)	11 (21%)	12 (28%)	12 (28%)
No. (%) > 15 µg/dL	3 (6%)	3 (6%)	7 (16%)	6 (14%)
No. (%) > 20 µg/dL	2 (4%)	1 (2%)	2 (5%)	6 (14%)

Table A.12-2. Median Blood-Lead Concentration (µg/dL) at Baseline and Follow-Up, by Study Group

Group	Baseline (interquartile range)	Follow-up (interquartile range)	Change (interquartile range)	Percent Change (interquartile range)
Intervention Group (n = 52)	6.85 (4.35, 9.9)	6.2 (3.95, 9.45)	-0.05 (-2, 0.7)	-0.8 (-24.3, 13.5)
Control Group (n = 43)	6.10 (4.2, 11.3)	6.2 (3.4, 10.4)	-0.6 (-1.9, 1)	-14.3 (-27.3, 20)

Among children who did not move, the median change in dust-lead levels, averaged across all surfaces was 45 µg/ft² and -67 µg/ft² for the Intervention and Control Groups, respectively. Among children who did not move and whose families used Ledisolv as instructed, the median difference in change in dust-lead loading, averaged across all surfaces was -7 µg/ft² and 2.7 µg/ft² for children whose families did not use Ledisolv. Both comparisons by group were found not to be statistically significant (p=0.41 and p=0.83). These results are summarized in Table A.12-3.

Table A.12-3. Median Change in Dust-Lead Loadings Averaged Across All Surfaces, for a Subset of 80 Children Who Lived in Same Residence at Baseline and Follow-Up

Measurement	By Treatment Group			By Use of Ledisolv		
	Intervention Group	Control Group	p	Did not use Ledisolv	Used Ledisolv	p
Median Absolute Change (µg/ft²) (interquartile range)	45 (-336, 1,921)	-67 (-4,382, 1,574)	0.41	2.7 (-2,004, 1,694)	-7 (-217, 555)	0.83
Median Percent Change (%) (interquartile range)	12.9 (-68.9, 158.2)	-27.3 (-63.8, 57.8)	0.43	8.1 (-59.6, 79.2)	-23.1 (-70.2, 80.2)	0.70

For measurements of specific areas of homes of children who did not move, a few comparisons showed significant or near significant differences by group. The median percentage change for dust-lead levels of non-carpeted floors was significantly greater among houses in the intervention group (p=0.08). For families using Ledisolv versus other families, the difference in median change in dust-lead levels on window sills was statistically significant (p=0.07). It was also noted that the baseline levels on window wells were also statistically different (p=0.05) for these groups. These results are summarized in Table A.12-4.

Table A.12-4. Median Change in Dust-Lead Loadings on Specific Surfaces, for a Subset of 80 Children Who Lived in Same Residence at Baseline and Follow-Up

Measurement	Surface	By Group			By Use of Ledisolv		
		Intervention Group	Control Group	P	Did not use Ledisolv	Used Ledisolv	P
Median Absolute Change (µg/ft²) (interquartile range)	Non-carpeted Floors	-9.9 (-19.7, -2.3)	-4.5 (-14.9, 1.1)	0.19	-5.8 (-16, -0.1)	-10.2 (-13.9, 2)	0.78
	Carpeted Floors	-6.9 (-10.2, -2.5)	-7.8 (-10.9, -0.9)	0.72	-7.9 (-10.8, -1.5)	-6.4 (-9.2, -2.6)	0.76
	Interior Window Sills	-58 (-154, -10)	-57 (-243, 19.4)	0.95	-47 (-208, 51)	-72 (-193, -21)	0.41
	Window Wells	261 (-1,027, 5,845)	-153 (-13,653, 5,627)	0.4	159 (-7,446, 6,044)	32 (-733, 2,369)	0.91
Median Percent Change (%) (interquartile range)	Non-carpeted Floors	-56.3 (-79.1, -26.1)	-31.7 (-67.7, 6.2)	0.08	41.6 (-68.1, -2.6)	-61.4 (-8.19, 13.6)	0.45
	Carpeted	-60.1 (-82.9, -30)	-46.6 (-80.3, -18.2)	0.46	-56.9 (-80.5, -19.8)	-55.5 (-71.9, -22.6)	0.81
	Interior Window Sills	-37.8 (-76.2, -7.6)	-39.4 (-77.2, 45.4)	0.82	-30.2 (-66.2, 53.4)	-63.8 (-81.4, -17.3)	0.07

	Window Wells	16.9 (-71.6, 139.2)	-33.1 (-62.6, 62.5)	0.41	7.7 (-58.3, 80.9)	-14.7 (-71.6, 121.6)	0.88

Conclusions (including caveats). The results indicate that educational intervention as conducted via providing families with simple dust control supplies and information on lead poisoning does not lower blood-lead concentrations for children with mild to moderate elevated blood lead more significantly than providing families with written information on the hazards and prevention of lead poisoning. Moreover, the documented declines are minor as compared to those resulting from other intervention strategies such as paint abatement and dust control.

Several possible sources of difficulty include: (1) Since dust control is a simple procedure, families in the Control Group may have taken it upon themselves to undergo dust control; (2) it has been shown that vacuuming of lead contaminated carpets may lead to short-term increase in children's exposure to lead-contaminated house dust (Ewers et al.); (3) it has been shown that blood-lead levels were more significantly reduced following lead hazard intervention for children with higher blood-lead levels than those with lower blood-lead levels. The mean blood-lead concentrations for children in this study were lower than that for most other studies; (4) the large variability of dust-lead levels between households in urban areas; and (5) the 7-month time span of the experiment may be susceptible to seasonal trends resulting in seasonal changes in blood-lead levels. A 12-month time span would minimize the effects of such trends.

It should be noted that a non-parametric approach was taken only after observing that one outlier in the Control Group, whose mean blood-lead level increased from 14.6 µg/dL to 55.8 µg/dL, affected the change in the mean blood-lead concentration for the control group from -0.55 µg/dL (95% CI= -1.61 to 0.51) without the outlier, to 0.42 with the outlier. The change in mean blood-lead level for the Intervention Group was -0.47 µg/dL (95% CI = -1.21 to 0.27).

A.13. Baltimore Repair & Maintenance Paint Abatement Study

Reference. U.S. Environmental Protection Agency (1995b), "Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Pre-Intervention Findings", EPA Report 747-R-95-012.

U.S. Environmental Protection Agency (1997), "Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on the First Year of Follow-up", EPA Report 747-R-97-001.

U.S. Environmental Protection Agency (1998a), "Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on Two Years of Follow-up", EPA Report 747-R-97-005.

Pertinent Study Objectives. This on-going study seeks to compare and characterize the short term (2-6 months) and longer term (longer than 12 months) effectiveness of three levels of repair and maintenance (R&M) interventions as a means of reducing childhood lead exposure. Children with blood lead concentration between 10 and 20 µg/dL were of primary interest as research on intervention strategies for such children is lacking.

Sampled Population. In January 1993, 107 non-Hispanic black households with low-to-moderate monthly rent or mortgage (mean $324) were selected from Baltimore City row houses. The 75 R&M households were similar in demographic characteristics and lead levels in blood and environmental samples. A target of 37 occupied houses were to be randomly assigned to either R&M Level I or II interventions and a target of 38 unoccupied houses were randomly assigned to either R&M level II or III interventions. The randomization scheme was designed to ensure each level consisted of 25 households. All unoccupied study homes were reoccupied post-intervention. Two control groups were utilized. One control group consisted of 15 households residing in older neighborhood housing which received comprehensive lead-paint abatement (PA) as part of a pilot abatement project in Baltimore between May 1988 and February 1991. The other control group consisted of 15 households residing in modern urban (MU) houses built after 1979 in modern urban subdivisions and hence, are presumably free of lead-based paint. The median age of children residing in the study homes ranged from 36 months to 43 months for the five groups at the 12-month follow-up. The study was also designed to enroll newborns during the follow-up phase once they reach the age of 6 months in order to assess the potential for primary prevention. As of the 24 month follow-up, 16 newborns had been added to the study (ranging in age from 6-18 months) and across all groups most of these children had blood lead concentrations less than 10 µg/dL.

Intervention Strategy. R&M Level I intervention, the least expensive and extensive intervention strategy, included wet scraping of deteriorating lead-based paint on interior surfaces, limited repainting of scraped surfaces, installing entryway mats, wet cleaning and vacuuming with a HEPA vacuum, exterior paint stabilization to the extent possible given budget considerations, and occupant and owner education. In addition, cleaning kits for the occupant's own cleaning efforts and the EPA brochure "Lead Poisoning and Your Children" were provided. R& M Level II intervention included, additionally, floor treatments that make them smooth and easier to clean and window and door treatments that reduce abrasion of lead painted surfaces. R&M Level III intervention further included window replacement, encapsulation of exterior window and door trim with aluminum coil stock and more durable floor and stairway treatments (e.g., coverings). The state agency funding the interventions imposed cost caps for R&M Levels I-III so the work to be done was prioritized and completed within cost constraints.

Measurements Taken. Interior dust samples were collected using a modified high volume cyclone sampler (HVS-3). Composite soil core samples were collected from three randomly selected locations. Dust and soil samples were analyzed using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP) and /or Graphite Furnace Atomic Absorption Spectrometry (GFAA). Water samples collected from first flush, 2 hours after running cold water for two minutes, were analyzed by GFAA. Venous blood samples were also analyzed by GFAA.

Study Design. This prospective 24-month study consisted of 7 sampling campaigns (rounds) conducted at Pre-R&M/Initial, Immediate Post R&M and 2, 6, 12, 18, and 24 months post R&M. Three interventions, R&M level I, R&M level II and R&M level III, were used in this study. The 75 R&M households were randomly assigned to these three interventions. The R&M Level I group consisted solely of families that lived in the abated homes prior to intervention, the R&M Level II group consisted of both families that lived in the abated homes prior to intervention and those that moved into homes unoccupied prior to intervention, and the R&M Level III group consisted solely of families that moved into homes unoccupied prior to intervention. As of the 24-month campaign, data were available from 21 households in the R&M Level I group, 22 in R&M Level II, 31 in R&M Level III, 14 MU control houses and 13 PA control households. The main outcome measurements were blood-lead concentration and dust-lead loading.

Study Results. Comparisons were based on figures for all children, regardless of whether or not they lived in the abated homes prior to intervention. One hundred twenty-seven children were available at baseline, with a loss of 27 due to moving and a gain of 9 via replacement recruiting, for a total of 109 at the 12-month campaign and a total of 123 at 24 months. Data for children whose blood lead concentration was not in the primary study range of 10 to 20 µg/dL were analyzed separately. At baseline there were 99 children with a blood-lead level < 20 µg/dL and 28 children with a blood-lead level 20 µg/dL. At the 12-month campaign there were 74 children with a blood-lead level < 20 µg/dL and 0, 8, 7, 11 and 9 children with a blood-lead level 20 µg/dL in the MU, PA, and R&M Level I , II and III groups, respectively. By 24 months, there were 130 children with blood-lead levels < 20 µg/dL and 19 were 20 µg/dL. Also, at 24 months there were 20, 20, 34, 27, and 29 children with blood lead levels < 20 µg/dL and 0, 3, 1, 8, and 7 children with levels 20 µg/dL in the MU, PA, and R&M Level I , II, and III groups, respectively.

Overall dust lead loading levels for all three R&M groups decreased from pre-intervention levels. The geometric mean, based on weighted averages of floor, entryway, window sill and window well samples decreased from 17542, 25214, and 478500 ($\mu g/ft^2$) at the Pre-Intervention/Initial campaign to 2364,1252, and 176 ($\mu g/ft^2$) at the 24-month campaign, for Level

I, II, and III R&M groups, respectively. Additional details on the dust-lead data are provided in Table B-3.

For all groups, the geometric mean of blood-lead concentrations appeared to decrease slightly from the pre-intervention campaign to the 12-month campaign. Pre-intervention geometric blood-lead levels decreased for all groups by 12 months post-intervention (Table A.13-1).

Table A.13-1. Geometric Mean Blood-Lead Concentration (µg/dL) By Group

Study Group	Initial	12 Month	24 Month *
R&M Level I (min, max) n	10 (2,22) 33	8 (2,20) 24	6 (2,15) 15
R&M Level II (min, max) n	14 (4,36) 32	11 (4,31) 30	10 (6,15) 12
R&M Level III (min, max) n	14 (2,42) 33	12 (4,30) 34	10 (6,15) 17
PA (min, max) n	13 (4,28) 23	12 (1,53) 24	10 ** (6,13) 12
MU (min, max) n	5 (2, 10)19	3 (2,6) 14	3 (2,6)15

* 24 month values are only for children with initial PbB < 20 µg/dL.
** excludes one child who received chelation at 12 months due to PbB of 53 µg/dL.

In attempting to characterize the relationship between blood-lead levels and possible influencing factors, several mixed models were fit to the data. The most relevant one, a comparison model (fit separately for children with PbB< 20 µg/dL and   20 µg/dL) , is

$$\ln(PbB)_{iklm} = \beta_0 + \beta_1{*}age_{iklm} + \beta_2{*}age^2_{iklm} + \beta_3{*}summer_{iklm} + \beta_4{*}male_{iklm} + \beta_5{*}group_k + \beta_6{*}campaign_l + b_i{*}house_i + b_{m(i)}child_{m(i)} + e_{iklm}$$

where β_0 -β_6 are coefficients for fixed effects and b_i and $b_{m(i)}$ are coefficients for random effects; with each coefficient measuring the rate at which one unit change in an effect changes the natural log of blood-lead concentration. Findings (for children with PbB< 20 µg/dL and controlling for age, gender, and season) based on this model are:

1. No statistically significant blood-lead differences were found between the three R&M groups during the two years of follow-up, except between R&M I and R&M III at two months.

2. Compared to the baseline, children in PA houses had no statistically significant changes in geometric mean blood lead concentrations during the two years of follow-up.

3. Children in MU houses had PbB levels that were statistically significantly lower than the other four groups. No statistically significant changes in children's blood lead concentration were found within this group during the two year follow-up.

Children with PbB 20 µg/dL tended to show a decrease in blood-lead concentration over time. These decreases were greatest between baseline and 12 months. Tables A.13-2 and A-13.3 display predicted blood lead concentrations at various campaigns. These numbers seem to fit well with the unadjusted results above.

Table A.13-2. Predicted Blood Lead Concentration (PbB, µg/dL) by Group and by Campaign in Children with Initial PbB < 20 µg/dL

Study Group	Initial Campaign Predicted PbB (95%) CI) n	2-Month Campaign Predicted PbB (95% CI) n	6-Month Campaign Predicted PbB (95%) CI) n	12-Month Campaign Predicted PbB (95%) CI) n	18-Month Campaign Predicted PbB (95%) CI) n	24-Month Campaign Predicted PbB (95%) CI) n
R&M 1	8.8 (7.5 to 10.2) 34	8.7 (7.3 to 10.3) 28	8.9 (7.5 to 10.5) 26	7.6 (6.0 to 9.6) 17	7.5 (5.7 to 9.8) 15	7.0 (5.4 to 9.0) 15
R&M II	10.5 (9.3 to 11.9) 27	11.2 (9.7 to 12.8) 20	11.6 (10.2 to 13.1) 21	10.3 (9.0 to 11.7) 18	10.2 (8.6 to 12.1) 15	9.4 (7.8 to 11.3) 12
R&M III	11.4 (10.0 to 13.0) 29	12.6 (10.6 to 14.8) 22	12.1 (10.4 to 14.2) 25	10.9 (9.4 to 12.8) 21	9.6 (8.2 to 11.3) 20	9.6 (8.2 to 11.1) 17
Previously Abated	11.8 (10.7 to 13.0) 20	N/A	14.0 (12.4 to 15.7) 18	12.4 (11.0 to 13.9) 17	12.4 (10.5 to 14.7) 13	10.2 (8.5 to 12.1) 13
Modern Urban	3.4 (2.9 to 4.0) 20	N/A	3.9 (3.2 to 4.7) 16	3.7 (3.1 to 4.3) 14	3.5 (2.9 to 4.2) 15	3.2 (2.7 to 3.8) 15

Table A.13-3. Predicted Blood Lead Concentration (PbB, µg/dL) by Group and by Campaign in Children with Initial PbB ≥ 20 µg/dL

Study Group	Initial Campaign Predicted PbB (95%) CI) n	2-Month Campaign Predicted PbB (95% CI) n	6-Month Campaign Predicted PbB (95%) CI) n	12-Month Campaign Predicted PbB (95%) CI) n	18-Month Campaign Predicted PbB (95%) CI) n	24-Month Campaign Predicted PbB (95%) CI) n
R&M 1	20.0 - 1	18.8 - 1	16.6 - 1	13.4 - 1	12.4 - 1	0
R&M II	28.3 (21.9 to 36.7) 7	22.7 (15.7 to 33.0) 4	19.0 (15.4 to 23.5) 7	16.2 (12.2 to 21.3) 6	15.1 (11.8 to 19.4) 7	14.5 (11.0 to 19.1) 6
R&M III	29.5 (24.8 to 35.1) 8	25.2 (21.3 to 29.9) 6	21.0 (17.4 to 25.5) 6	18.2 (14.6 to 22.6) 6	17.2 (13.8 to 21.3) 6	15.5 (12.3 to 19.7) 6
Previously Abated	29.1 (22.3 to 37.9) 3	Not applicable	22.6 (20.4 to 25.0) 3	19.6 (14.5 to 26.4) 3	18.5 (15.1 to 22.8) 3	16.8 (13.7 to 20.7) 3
Modern Urban	0	Not applicable	0	0	0	0

Conclusions (including caveats). The lack of a significant change in the geometric mean of blood-lead concentrations of children with initial levels < 20 µg/dL for all five groups could be a result of the fact that initial blood-lead levels were already at low to moderate levels. Cumulative body lead burdens may also be a factor that mediated the children's blood lead responses to the R&M interventions. Comparisons were made based on group assignment, regardless of whether or not the child lived in the abated home prior to intervention. All R&M Level I children lived in the same home prior to intervention, while all R&M Level III children did not move in until after invention. Thus, it is not clear whether changes in blood-lead levels were due to pre-intervention residence or due to group assignment. An attempt was made to control for this possible confounding factor by comparing children with similar baseline blood-lead levels. Although these groups still may not be comparable, it is worth noting that children with baseline PbB 20 µg/dL showed declines in blood-lead levels over time, while children with baseline PbB < 20 µg/dL tended to remain below 20 µg/dL. Although decreases in blood-lead concentration were statistically significant at the 12- and 24-month campaigns for children with baseline PbBs 20 µg/dL in the R&M II and III and PA groups, any conclusion should be made with caution as the sample size of such children for each group was small (n=0,8,7,11 and 9 for MU, PA R&M I, II, and III groups, respectively).

A.14. <u>New Zealand Retrospective Paint Abatement Study</u>

Reference. Bates, M.N., Wyatt, R., Garrett, N. (1997) "Old Paint Removal and blood lead levels in children." *New Zealand Medical Journal*. 110(1053):373-377.

Pertinent Study Objectives. This study sought to identify risk factors for elevated blood lead levels in children, particularly which lead paint removal and clean up practices pose the greatest risk.

Sampled Population. The sampled population were children aged 12-24 months from Wellington, New Zealand, living in homes more than 50 years old where interior or exterior paint removal had taken place in the last two years. To be eligible, the child must have been living in the residence for at least six months. One hundred eighty-seven children were identified as eligible, and the caretakers of 141 of these children agreed to let them participate in the study.

Intervention Strategy. The method of lead paint removal was up to the resident. Abatements were performed by either the resident or a contractor. Strategies included: chemical stripping, scraping by hand, various types of sanders, electric heat guns, waterblasting, and blowtorching.

Measurements Taken. A licensed phlebotomist visited each participating family and collected a venous sample of blood from the child using a standard protocol. A dust sample was collected from the kitchen floor using a standard wipe sampling procedure. Finally, a questionnaire was administered to the caregiver, and dealt with subjects like the child's health, development and normal behaviors, the parental hobbies and occupations, and the paint removal and clean up that had taken place. If the paint removal had been performed by a contractor, that person was contacted to answer the questions about removal and clean up.

Study Design. This retrospective study assessed risk factors, particularly paint removal and clean up practices, for elevated blood lead levels in children. No abatements were performed , however, homes of participating children had been abated which two years preceding data collection. Information about paint removal and clean up methods was used to assess risk. Care givers were interviewed, a blood sample was collected from the child's arm, and a dust wipe sample was collected from the kitchen floor. Blood and dust samples were analyzed for lead content. The main outcome measurement was blood-lead concentration.

Study Results. From the results of a previous study, a ratio of 1:3 of high lead (blood lead 10 µg/dL) to low lead (blood lead < 10 µg/dL) blood levels were expected. Thus, it was proposed to enroll about 200 children in the study, which would yield approximately 50 children with elevated blood-lead levels and 150 children with low blood-lead levels, which would be sufficient to perform the desired statistical analyses. The overall geometric mean blood-lead level in the 141 children participating in the study was 5 µg/dL. Only 11% had blood lead levels exceeding 10 µg/dL, less than the 25% expected. Therefore, to provide their statistical analysis with sufficient power the authors redefined high blood-lead levels as those 7.2 µg/dL and low blood-lead levels as < 7.2 µg/dL.

The authors first looked for demographic differences in the blood-lead levels. After examining the number of high and low lead children with respect to gender, ethnicity, age (12-18 months vs. 19-24 months), and income (less than $30,000, between $30,000 and $40,000, and more than $40,000), it was found that significant differences existed only with regard to income. Higher income was associated with lower blood-lead levels. They also found that several parental hobbies, like making stained glass or lead lighting and making lead shot or ammunition, were associated with elevated blood-lead levels.

The abatement data were analyzed separately, depending on whether paint was removed from the interior or exterior of the dwelling. Table A.14-1 shows some results for exterior paint removal, and includes work done either by family and friends or by contractor.

The differences in the blood lead levels of children exposed vs. children not exposed were not significant for any particular paint removal method, except that there was an association with the use of a blow torch for paint removal and elevated blood-lead levels, when work done by contractors was not included in the analysis. Results for the interior paint removal were reported to be similar to those for the exterior work. Once again, none of the methods seemed to be associated with high blood-lead levels except for one case where a blowtorch was used. Finally, none of the clean up or disposal methods for old paint that were examined were associated with high blood- lead levels. Detailed results for interior paint removal and cleanup methods were not provided.

Table A.14-1. Blood-Lead Concentration (µg/dL) by Initial PbB and Exterior Paint Removal Method (Total Subjects = 80)

Paint Removal Method	Response	N	Blood Lead Levels (µg/dL)			
			# Children 7.2	# Children < 7.2	Geometric Mean (GM)	P-Value for Comparison of GM
Chemical paint stripper?	Yes	6	1	5	4.6	0.63
	No	74	20	54	5	
Sanding/Scraping by Hand?	Yes	80	21	59	5	N/A
	No	0	0	0	N/A	
Machine sander?	Yes	43	12	31	5	0.97
	No	37	9	28	5	
Blow torch?	Yes	8	3	5	7	0.08
	No	72	18	54	4.8	
Blow torch? (excluding work done by contractors)	Yes	3	3	0	15.5	0.0003
	No	63	17	46	5	
Electric heat gun?	Yes	28	9	19	5.8	0.16
	No	52	12	40	4.8	
Waterblasting?	Yes	16	6	10	5.8	0.25
	No	64	15	49	4.8	

Conclusions (including caveats). The primary objective of this study was to identify specific paint removal and clean up practices that were associated with children's elevated blood-lead levels. The analysis of the results indicated that none of methods used in paint removal or clean up were strongly associated with elevated blood-lead levels, except for methods involving a blow torch. This is not surprising as the use of high-temperature methods are known to be risky and generally are not used, as they have been replaced by safer alternatives. The risk with this method appeared to be particularly great when performed by family or friends, as opposed to contractors. It should be noted that only a small number of people in the study used blowtorches, which somewhat lessens the strength of the conclusions from this set of data.

The authors note that a number of weak, non-statistically significant results suggested that abatement work done by family and friends was more likely to be associated with elevated blood-lead levels than work done by a contractor. This result could, however, be due to selection bias, as 30% of the contractors were not available for interview.

Finally, another notable result was the strong association of elevated blood-lead levels with several parental hobbies. Four of the five children with the highest blood-lead levels had parents with hobbies involving the use of lead, in particular, glazing pottery and ceramic work and the making of lead shot and ammunition. However, this apparent association is confounded with the fact that two of these four children lived in homes where a blowtorch had been used in the paint removal. Since the number of families with hobbies involving lead was so small, it was impossible to assess the relative importance of this factor.

A.15. East St. Louis Educational Intervention Study

Reference. Copley C. (1995) "East St. Louis Lead Dust Reduction in Homes of At-Risk Children." Report on Grant NE995974-01 to U.S. Environmental Protection Agency, October 1995.

Copley, C. (1996), Personal Communication. June 1996.

Pertinent Study Objectives. This study sought to determine whether an educational intervention, which provided in-home instruction and identification of problem areas, could be successful in reducing household dust-lead levels in a low socio-economic status, multi-ethnic community.

Sampled Population. Most residents of this predominantly African-American community receive some form of public assistance. Children, with blood-lead concentrations between 10 and 19 µg/dL, were identified through a screening program for children receiving public assistance. Fifty-four homes were included in the study. These households consisted of approximately 124 young children and 117 adults.

Intervention Strategy. During the initial visit, an XRF paint survey was conducted and areas with high lead loadings were pointed out to the residents. Lead educators, hired from within the community, provided instruction on cleaning and hygiene. Written materials and a videotape on reducing lead exposure were also provided. Participating families were contacted regularly throughout the course of the study to reinforce the importance of regular, thorough cleaning.

Measurements Taken. Environmental samples were collected at the initial visit. Three-month follow-up samples were collected in homes where the residents reported that they had cleaned at least once using the recommended procedures. At each visit, at least three dust wipe samples were collected from smooth surfaces in the home. In addition, two vacuum (HVS-3) samples were collected from carpets in the entry and bedroom, or other play area. Follow-up blood samples were not collected.

Study Design. Fifty-four homes of children with moderately elevated blood-lead levels were included in the study. An educational intervention, which consisted of an in-home educational visit, was provided to participating families. The main outcome measurement was dust-lead loading.

Study Results. After repeated follow-up calls only 24 of the 54 families reported that they had cleaned at least once during the three months using the recommended procedures. A total of 1,166 surfaces were tested for lead-based paint in the 55 homes, of which 342 surfaces tested positive, including 197 exterior and 145 interior surfaces. In addition to lead paint surveys, dust samples were collected from 164 smooth surfaces and from 69 carpets. Of the 164 smooth surfaces tested, 75 samples were below the detection level of 5 µg/ft^2, and of the remaining 89 samples, only 46 had dust-lead levels greater than 200 µg/ft^2 (Illinois clearance standard). Comparison of lead dust concentrations prior to cleaning and after at least one conventional cleaning effort revealed a 56 percent decrease in arithmetic mean dust-lead loadings on smooth surfaces and a 68 percent decrease on carpets (Table A.15-1). Mean floor dust-lead loadings decreased from an average of 1,095 µg/ft^2 to 486 µg/ft^2 for the 30 smooth surfaces which had been cleaned at least one time by the residents, while the geometric mean decreased from 454 µg/ft^2 to 58 µg/ft^2. The mean carpet dust-lead loading decreased to 725 µg/ft^2 from 2,268 µg/ft^2 and the geometric mean declined to 16 µg/ft^2 from 1,143 µg/ft^2 at the three-month follow-up measure.

Table A.15-1. Floor Dust-Lead Loading (µg/ft^2) by Surface Type and Sampling Round

Sample Type	Parameter	Initial Sample	Follow-up Sample	Difference Between Initial and Follow-up
Smooth Surfaces	Arithmetic Mean	1,095	486	-56 %
	Geometric Mean	454	58	-87 %
	N	(30)	(30)	---
Carpet (HVS-3)	Arithmetic Mean	2,268	725	-68 %
	Geometric Mean	1,143	16	-99 %
	N	(27)	(27)	---

Conclusions (including caveats). This study suggests education and residential cleaning by the homeowner can be effective in reducing dust-lead levels in the home thereby, hopefully, reducing children's lead exposure. The results suggest that it is easier to control dust levels on smooth surfaces rather than carpets. However, educational interventions rely on the initiative of the family to implement the recommended procedures. In this community, many families did not follow through and their children may not have benefitted from the educational intervention.

A.16. <u>HUD Abatement Grant Program</u>

Reference. The National Center for Lead-Safe Housing and The University of Cincinnati Department of Environment Health. "Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program", Fourth Interim Report. Prepared for U.S. Department of Housing and Urban Development. March 1997.

The National Center for Lead-Safe Housing and The University of Cincinnati Department of Environment Health. "Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program", Fifth Interim Report. Prepared for U.S. Department of Housing and Urban Development. March 1998.

Pertinent Study Objectives. This ongoing study seeks to determine the effectiveness of the various abatement methods used by State and local government HUD grantees to reduce lead-based paint hazards in housing.

Sampled Population. There are 83 state and local government agencies participating in the HUD Lead-Based Hazard Control Grant Program. However, due to budgetary constraint, only 14 out of the 83 grantees are participating in the formal evaluation of the program and consist of: Alameda County, CA; Baltimore, MD; Boston, MA; California; Chicago, IL; Cleveland, OH; Massachusetts; Milwaukee, WI; Minnesota; New Jersey; New York City, NY; Rhode Island; Vermont; and Wisconsin. It was HUD's desire to emphasize local control of the individual programs, so each grantee is responsible for designing a program applicable to its specific needs and objectives; including how dwellings are enrolled. Thus, enrollment criteria varied between the different grantees and included targeting high-risk neighborhoods, enrolling only homes with a lead-poisoned child, and considering unsolicited applications. The specific criteria used by each of the grantees and the current number of units enrolled are summarized in Table A.16-1. Through September 1, 1997, there were 3,556 dwellings (only 2,900 will be part of the evaluation however), 2,432 households, and 1,933 children under age six enrolled by the 14 reporting grantees.

Intervention Strategy. In this study, grantees were given the flexibility to select the type and intensity of the lead treatments for any particular unit. The intensity of an intervention is reported by location (interior, exterior, or site) and consists of a number representing the type of intervention performed in that location. The interventions range from taking no action, and simple cleaning, to window replacement or full lead-based paint abatement. Table A.16-2 summarizes the different strategies available for each location. Some cost information was reported. For example, the median lead hazard control and total project cost of a level 02 interior cleaning intervention was $721. As additional work was performed, median costs increased to $5,000 (level 03), $7,604 (level 04), and $9,935 (level 05) for the total cost of lead hazard intervention, by level of interior intervention strategy.

Measurements Taken. All grantees recorded the basic characteristics of the dwelling unit and resident household, the dwelling condition, paint inspection and dust sample information, the type of intervention performed, family interview and occupant protection/relocation information, and blood lead results. The collection of soil-lead measurements was optional. The grantees followed the same sampling protocols when collecting the data, and used standard forms developed specifically for the evaluation.

Table A.16-1. Enrollment/Recruitment Criteria of the HUD Grantee Programs

Grantee	Enrollment Plan	Number of Units Enrolled
Alameda County	Targeting 4 high-risk cities, many units contain a lead-poisoned child	223
Baltimore	Targeting 3 neighborhoods, two of which have histories of lead-poisoning	561
Boston	Enrolling only units which have received an order to abate based on the identification of a lead-poisoned child	111
California	Targeting older homes in low-income neighborhoods	129
Chicago	Targeting 5 neighborhoods; units are selected based on reports of a lead-poisoned child	156
Cleveland	Sub-grantee 1 - targeting units with a lead-poisoned child; sub-grantee 2 - targeting homes in one neighborhood	205
Massachusetts	Primarily enrolling units under existing orders to abate because of the presence, at some time, of a lead-poisoned child	154
Milwaukee	Targeting several of the lowest income neighborhoods; units are selected from referrals of families with a lead-poisoned child	364
Minnesota	Sub-grantees 1 and 2 - targeting units with a lead-poisoned child; Sub-grantee 3 - targeting units with deteriorated housing conditions	191
New Jersey	Selecting units in conjunction with concurrent comprehensive housing renovation/rehabilitation	105
New York City	Targeting neighborhoods with the highest percentages of lead poisonings; one of two programs is specifically targeting families with newborn babies living in deteriorated housing	333
Rhode Island	Enrolling only units that meet Section 8 Housing Quality Standards, and the owner cannot own more than 12 units	198
Vermont	Considering referrals of families with lead-poisoned children, nonprofit housing developers who learn of the program when applying for federal HOME funds, and unsolicited applications	583
Wisconsin	Each of the 12 sub-grantees within the state uses own criteria (not defined in this report)	243

Table A.16-2. Intervention Strategy Codes and Descriptions

Strategy		Definition
Interior	1	No Action
	2	Cleaning, Spot Paint Stabilization Only
	3	Level 02 plus Complete Paint Stabilization, Floor Treatments
	4	Level 03 plus Window Treatments
	5	Level 04 plus Window Replacement, Wall Enclosure/Encapsulation
	6	All Lead-Based Paint Enclosed, Encapsulated, or Removed (Meets Public Housing Abatement Standards)
	7	All Lead-Based Paint Removed
Exterior	0	No Action
	1	Spot or Partial Paint Stabilization
	2	Complete Paint Stabilization, Porch Treatments
	3	Level 02 plus Porch/Trim Enclosure, Stabilization or Encapsulation
	4	All Lead-Based Paint Enclosed, Encapsulated, or Removed
	5	All Lead-Based Paint Removed
Site	0	No Action
	1	Cover Soil with Temporary Cover (Mulch, Stone)
	2	Level 01 plus Seed, Install Barriers (Bushes, Fencing)
	3	Level 02 plus Partial Soil Removal, Plant Sod
	4	Complete Soil Removal or Enclosure with Asphalt, Concrete

Study Design. Grantees gathered information four times during this prospective study: prior to intervention, immediately after intervention, 6 and 12 months after intervention. In addition, to fully assess the costs and benefits of the different strategies, nine grantees were selected to collect data at 24 and 36 months after intervention. The participants in this follow-up study are Alameda County, Baltimore, Boston, California, Minnesota, Rhode Island, Wisconsin, Milwaukee, and Vermont. The method of intervention assignment varied, as the grantees were allowed to select the type and intensity of the lead treatment for each dwelling. The primary outcome measurements to be studied are the dust-lead loadings from floors, window sills, and troughs, and the enrolled children's blood lead levels.

Study Results. Through September 1, 1997, interventions had been completed in 2,297 of the 2,900 enrolled dwelling units. Information on the interior strategies was available for 1,506 units, and results indicate that 69% of the units have received treatments that include partial or complete replacement of windows (levels 04-05) rather than lower level interventions like specialized cleaning and the stabilization of deteriorated paint (levels 02-03). However, either no interior work (level 01) or full abatement of the lead hazards (levels 06-07) was conducted in fewer than 4% of the units.

Information on exterior strategies was available for 810 buildings. In about 16% of these buildings, no action was taken, and approximately 9% had a full abatement performed (levels 04-05). The majority of grantees chose to perform mostly (60%) partial or complete stabilization of lead-based paint (levels 01-02). Of the 787 buildings with site/soil strategies reported, 686 (87%) received no soil treatment. When a site intervention was performed, it was most commonly a low level strategy like providing soil with a temporary cover such as mulch (level 1).

Dust sampling results are reported for occupied dwellings, where the effectiveness of lead interventions can be examined without the confounding effects of vacancy (vacant residences have been estimated to have higher dust-lead loadings). The changes in dust-lead loadings from pre-intervention (Phase 1) to immediate post-intervention (Phase 2), six months post-intervention (Phase 3), and twelve months post-intervention (Phase 4) are presented in Table A.16-3 for floors, window sills, and window troughs.

Table A.16-3. Median Dust-Lead Loadings (µg/ft^2) and Percent Declines by Study Phase and Location

Location	#Units	Median Dust-Lead Loading (µg/ft²)				Percent Decline (Phase 1 to 2)	Percent Decline (Overall)
		Phase 1	Phase 2	Phase 3	Phase 4		
Floors	892	20	18	14	N/A	10	30
	557	19	17	14	14	11	26
Window Sills	877	257	46	81	N/A	82	68
	547	258	52	97	90	80	65
Window Troughs	731	11559	54	603	N/A	99	95
	448	14350	61	770	657	99	95

Dust-lead loadings from Phases 1 through 3 for floors were available from 892 occupied dwellings, and while interventions were found to have a small impact on median dust-lead loadings (20 µg/ft^2 pre-intervention and 18 µg/ft^2 immediately after), they did appear to greatly reduce levels at the upper end of the distribution. For example, the 90th percentile floor dust-lead loading was reduced by 67% from 150 to 50 µg/ft². The reported changes in the median level may have been limited by the analytical limits of detection. In the 557 occupied dwellings with 12 months post-intervention data, the overall Phase 4 levels were lower than Phase 1 and there was little indication of reaccumulation from Phase 2 to Phase 3 or Phase 3 to Phase 4.

Phase 1 through 3 dust-lead loadings for interior window sills were available for 877 occupied dwellings and there was an 82% decline in the median lead loading from Phase 1 to Phase 2. In contrast to the results from the floor lead loadings, window sill lead loadings had a tendency to rise from Phase 2 to Phase 3 and from Phase 2 to Phase 4 in the 547 dwellings with this data available. However, because of the large reduction in levels from Phase 1 to Phase 2, the Phase 3 and Phase 4 loadings are still substantially lower than pre-intervention levels (65% decline). There was also an unexpected slight decline in levels between Phase 3 and Phase 4. It should be noted that the declines were usually very small and within the margin of error of the dust wiping protocols. Yet, even if the decreases are the result of sampling variability, there is still strong evidence there was little change in the dust lead levels between Phases 3 and 4.

Dust-lead loadings for window troughs from Phases 1 through three were available from 731 dwellings and there was a substantial (99%) decline in the median levels, as well as in the low and high ends of the distribution. In 448 dwellings with window trough results for Phases 1-4, there was greater than a tenfold increase in the median dust-lead loading between Phases 2 and 4. Although the median lead loading remained below the clearance level of 800 µg/ft², the 90th percentile rose from 319 µg/ft² to 8,170 µg/ft² between Phases 2 and 4. Despite this increase, the Phase 4 levels were much lower than pre-intervention levels. The window trough loadings also showed a decline between Phases 3 and 4, similar to that seen in the window sills.

Pre-intervention (Phase 1) and 6-month post-intervention (Phase 3) blood lead results were available for 541 of the 1,933 children under age 6 enrolled and 12-month post-intervention (Phase 4) results are available for 338 children. These results are detailed in Table A.16-4. In this preliminary stage, blood-lead results were presented in terms of the number of children whose Phase 1 vs. Phase 3 and Phase 1 vs. Phase 4 blood lead levels were the same (<3 µg/dL difference), had a "small" difference (>3 µg/dL to 6 µg/dL), or had a "large" difference (>6 µg/dL). The blood lead changes were adjusted to reflect the expected changes due to the time of year (season) and the child's age. The percentage of children who had no change (defined as < 3 µg/dL due to measurement error) in adjusted blood-lead levels was approximately 60% between Phases 1 and 3 and was about 50% between Phases 1 and 4. About five times as many children had "small" decreases (17.6%) than had "small" increases (3.5%), and approximately four times as many had "large" decreases (16%) than had "large" increases (4%) between Phase 1 and Phase 3.

Table A.16-4. Change in Children's Blood Lead Levels (µg/dL) Pre-Intervention (Phase 1) to Six Months Post-Intervention (Phase 3) and Twelve Months Post-Intervention (Phase 4)

		Change in Blood Lead (µg/dL) Level					
		< -6	< -3 to -6	-3 to 3	> 3 to 6	> 6	Total
Phase 3 - Phase 1	Number of Children	86	95	321	19	20	541
	Percentage of Children	15.9	17.6	59.3	3.5	3.7	100
Phase 4 - Phase 1	Number of Children	72	80	168	12	6	338
	Percentage of Children	21.3	23.7	49.7	3.6	1.8	100

Conclusions (including caveats). This study is one of the largest and most comprehensive ever initiated. Data collection began in 1994 and will continue until 1999. This report only contained analysis of data collected as of September 1, 1997, and so results should be considered preliminary. In terms of dust-lead loading, the interventions performed seem to be very effective at immediately reducing window sill and trough dust-lead levels and very high floor dust-lead levels. The effect on the median floor dust-lead level was not apparent, and could be due to the fact that the pre-intervention levels were relatively low. Reductions at low levels may commonly be underestimated, as laboratories have limits on how much leaded dust can be detected. Floors showed little reaccumulation of lead dust through six months post-intervention, and while some lead dust did reaccumulate in the window sills and troughs, there was still a net reduction in dust lead from pre-intervention levels. The declines seen between Phases 3 and 4 in window sills and troughs need to be further investigated, as they may possibly have been influenced by the season, or the study design. The study protocol called for half of a window to be wiped in Phase 2, the other half to be wiped in Phase 3, and then the original half wiped again in Phase 4. Therefore, the half that wiped in Phase 4 had also been wiped immediately after intervention, while the Phase 3 half had not. The specific protocols have not always been followed consistently, but at this time the possible effects of the study design cannot be ruled out. However, the results still suggest that the interventions are reducing one of the largest sources of exposure for children, and that the benefits of the interventions are greatest in homes and on surfaces with the highest levels of contamination. It was also found that 28% of units did not pass clearance for at least one component on the first try. This not only reinforces the importance of performing clearance tests, but suggests that a further analysis of the causes of failure are needed. Failures can have a substantial financial impact due to the cost of re-cleaning and re-testing the dwelling and the continued relocation of the families. Understanding the cause of the failure can help to prevent them and avoid these costs.

The changes in blood-lead levels are not considered the primary outcome measure in this study because they are susceptible to so many factors. At six months post-intervention, 59% of the children had blood lead levels essentially the same as their pre-intervention level. However, the authors note that this result is not surprising as many of the enrolled children were previously exposed to lead and may have had high internal body stores of lead. For such children, blood-lead levels may change very slowly, even if the source of lead exposure is eliminated. For the children whose blood-lead levels did change, there were almost five times as many decreases than increases at 6 months post-intervention, and 8 times as many decreases than increases at 12 months post-intervention.

Finally, an ideal research project designed to test the effects of environmental intervention techniques on dust-lead and blood-lead levels over time would have a randomly selected group of units to be treated, and a control group that is similar. However, such research strategies were not compatible with the program's intent to have flexible, locally designed treatment strategies. Therefore, some additional data was collected so changes in lead levels could be determined to be the result of the lead hazard work and not other factors. Even so, the findings from the evaluation will have to be interpreted carefully and causal relationships that may be implied by the results will require confirmation in a more controlled investigation.

A.17. Canadian Community-wide Approach (3 Studies)

A.17a. Toronto Soil and Dust Abatement Study

Reference. Langlois, P. and Gould, R. (1996) "Blood Lead Levels in Toronto Children and Abatement of Lead-Contaminated Soil and House Dust." *Archives of Environmental Health*. 51(1):59-67.

Pertinent Study Objectives. This study sought to determine the impact of a large, community-wide abatement program that removed lead-contaminated soil and house dust from most homes in the community.

Sampled Population. Study homes were located in the South Riverdale suburb of Toronto, near an active secondary lead smelter. Children who resided within the boundaries of the community-wide abatement program area were included in the study, whether or not their home was abated. Two control populations were identified: 1) a sociodemographically similar population of children who resided in South Riverdale, but not near the smelter, and 2) a sociodemographically dissimilar population of children who attended one of five Toronto schools. All study children were under 6 years of age.

Intervention Strategy. Soil abatement consisted of removal of the top 30 cm of soil from areas where the soil-lead concentration exceeded 500 ppm. No details of the dust cleaning intervention were provided.

Measurements Taken. Blood-lead measurements were collected via finger prick samples, in community screenings in 1984, 1987, 1988, 1989, 1990, and 1992 in the South Riverdale study (SRS) area; in 1988 and 1990 in the South Riverdale control (SRC) area; and in 1984, 1988, 1990, and 1992 at five Toronto schools. Soil-lead concentrations in the SRS area were utilized in the analysis, but not reported.

Study Design. Three groups, the South Riverdale Study (SRS), South Riverdale Control (SRC), and Toronto Schools Control (TSC), were followed in this study. The Intervention methods used were soil abatements and housecleaning. Soil abatements were performed between May and October 1988, for nearly 970 properties in South Riverdale that qualified for the soil abatement program. Professional housecleaning was performed between April and November 1989 for the 717 households that accepted this service. The main outcome measurement was blood-lead concentrations.

Study Results. Blood-lead concentrations decreased over time in all study groups (Table A.17a-1). Although the SRS area had higher blood-lead concentrations than the control areas prior to abatement, by 1992, the SRS mean blood-lead concentration was no longer significantly greater than the Toronto Schools control means. Prior to abatement, blood-lead levels in the SRS area did not decrease as quickly as in the Toronto Schools control (TSC) area. However, in the post-abatement period, blood-lead levels in the SRS area dropped significantly more quickly than in the TSC area.

Table A.17a-1. Summary of Blood-Lead Concentrations in Study Communities

Study Group	Year	Sample Size	Mean PbB (µg/dL)	Number of Children (Percent): 10 µg/dL	20 µg/dL
South Riverdale Study (SRS)	1984	214	14	183 (86)	39 (18)
	1987	154	10.9	87 (57)	17 (11)
	1988	136	9.3	58 (43)	1 (1)
	1989	162	6.5	29 (18)	3 (2)
	1990	148	6.4	24 (16)	1 (1)
	1992	110	3.9	8 (7)	0 (0)
South Riverdale Control (SRC)	1988	157	7.1	36 (23)	3 (2)
	1990	177	4.2	7 (4)	0 (0)
Toronto Schools Control (TSC)	1984	173	11.9	119 (69)	13 (8)
	1988	258	5.1	18 (7)	2 (1)
	1990	249	3.6	8 (3)	1 (<1)
	1992	222	3.5	18 (8)	1 (1)

Additional analyses were conducted using blood lead data from the SRS area. SRS children were categorized into one of four abatement groups: (a) soil abatement, (b) dust abatement, (c) both soil and dust abatement, and (d) no abatement. Multiple blood-lead measurements from 160 children (415 samples) and single measurements from 500 children were analyzed together, under the implicit assumption that all measurements were independent. On average, throughout the study period, children with no abatement had the lowest blood-lead concentrations. In addition, blood-lead concentrations for children with no abatement declined more rapidly than for those in the abatement groups. This result was reported consistently by several models fitted by the authors. Because the blood-lead screening took place while abatements were ongoing, comparisons were made between children who had received the abatement and those who had not yet received the scheduled abatement. No significant differences were reported for these comparisons. No attempt was made to assess the effect of the intervention using pre- and post-intervention measures from the same children.

Conclusions (including caveats). Although the SRS area had higher blood-lead concentrations than the control areas prior to abatement, by 1992 the SRS mean blood-lead concentration was no longer significantly greater than the TSC mean. Despite the abatement, blood-lead levels in the SRS and SRC areas declined by about the same amount between 1988 and 1990. In the post-abatement period, blood-lead levels in the SRS area dropped significantly more quickly than in the TSC area. These results suggest that the intervention was effective in reducing blood-lead concentrations in the community. However, within the SRS area, children with no abatement had the lowest blood-lead concentrations. In addition, blood-lead concentrations among these children declined more rapidly on average than among those in the abatement groups. The validity of these results is unclear, as multiple, positively correlated, measurements over time from some children were analyzed together with single measurements from other children and treated as independent measurements. Within the SRS area, 45% of the data were not independent. The authors suggest, based on a sensitivity analysis, that selection bias could explain some of the differences in trends among the abatement groups. Although multiple blood-lead measurements were available, no attempt was made to assess the effect of the intervention using pre- and post-intervention measures from the same children.

A.17b. St. Jean-Sur-Richelieu Soil and Dust Abatement Study

Reference. Goulet, L., Gaudreau, J. and Messier, A. (1996). "Results of a Lead Decontamination Program," *Archives of Environmental Health*, 51(1):68-72.

Pertinent Study Objectives. The purpose of this study was to evaluate the impact of a community-wide soil and house dust abatement intervention undertaken in a residential area near a battery reclamation plant.

Sampled Population. Two contaminated residential areas of St-Jean-sur-Richelieu, Quebec were identified based on surface soil sampling conducted in May 1989. Area 1, located 150 meters from the plant, was more severely contaminated than Area 2, which was located 150 to 600 meters from the plant. Children who were six months to ten years of age and who lived within 600 meters of the battery reclamation plant were identified for the public health program. Blood-lead concentrations were measured in 510 children (approximately 81.6% of those eligible) in the 1989 survey, including 169 who lived in Area 1.

A second epidemiologic survey was conducted to evaluate the impact of the public health program on the blood-lead levels of the children living in Area 1, at the end of August 1991. Of the 101 children tested in 1991 (79.2% of those eligible), 75 had their blood-lead levels tested in 1989, 11 were born after 1989, and 9 had moved to the area after 1989.

Intervention Strategy. In August-September 1989, the plant was closed and the plant yard was asphalted, thus eliminating the source of lead. A public information campaign provided information on the sources and dangers of lead. Between October 1989 and March 1990, 115 houses in areas 1 and 2 that housed children with blood levels 15 ug/dL were cleaned professionally. The cleaning operations included HEPA vacuuming of ceilings and walls, heating and air-conditioning ducts, floors, window seals, carpets, and furniture surfaces. Carpets and furniture were steam-cleaned twice and floors were also damp-mopped twice. All accessible objects were washed prior to reuse, and clothing in closets were vacuumed. Other intervention strategies were specific to each area:

1. Area 1: In September 1989 the street dust was removed. Between 10 and 30 cm of all accessible surfaces were moved and replaced, except grass and gravel, regardless of lead concentration. Grass and gravel with lead concentrations 500 ppm or greater were replaced. Between March 1990 and December 1992, homes with children who were 0-6 years of age or with pregnant women were offered professional cleaning services, if they had not been cleaned in the previous phase. In addition to the overall public-information campaign, individual meetings were conducted with parents of children who were less than 6 years of age.

2. Area 2: Accessible surfaces were replaced if lead concentrations exceeded 400 ppm, and grass and gravel were replaced if lead levels were equal to or greater than 1,000 ppm.

Measurements Taken. Blood samples were taken by venipuncture, using 3-mm pediatric vacutainers. Blood-lead levels were determined by flameless atomic absorption spectrophotometry. Information on the demographic and behavioral characteristics of the children and their parents was collected by interviewers trained for that purpose. A total of 28 surface soil (0-5 cm), 4 household dust, and 6 water samples were collected in May 1989. Details on additional environmental sampling were not reported.

Study Design. Two areas of contamination were included in the study. Area 1, located within approximately 150 m from the plant site, was contaminated severely; and area 2, which was 150-600 m from the plant site, showed less contamination. At the end of September 1989, an epidemiologic survey was conducted to evaluate the effect of the contamination on the health of the children. Interventions began in September 1989, as well. House cleaning interventions were conducted between October 1989 and March 1990 in homes of children with blood-lead levels greater than 15 µg/dL. House cleaning was provided to all other children less than 6 years of age and to pregnant women between March 1990 and December 1992. At the end of August 1991, a second epidemiologic survey was conducted in area 1 to evaluate the impact of the public health program on the blood lead levels of the children. This study provides the results of both survey.

Eligible participants were children, who were 6 months to 10 years of age who lived in area 1 as of August 1991. Municipal census listings were used to identify all eligible children. Parents were reached by personal phone calls and an extensive information campaign was conducted in the local media. Information on the demographic and behavioral characteristics of the children and their parents was collected by interviewers trained for that purpose. Activities for intervention included asphalting the plant yard, removing dust from the roads and sidewalks, removing and replacing the contaminated soils, professional cleaning of the houses, and implementing a public health-education campaign. The main outcome measurement was blood-lead concentration.

Study Results. The mean blood-lead concentration of children who were 6 months to 10 years of age and who participated in both surveys (n=75) dropped from 9.7 µg/dL in 1989 to 5.0 µg/dL in 1991 (Table A17b-1). The mean blood-lead concentration for children aged 6 months to 5 years in 1991 decreased from 9.8 µg/dL in 1989 to 5.5 µg/dL in 1991. The differences were statistically significant ($p<0.0001$). In 1991, none of the children had blood-lead levels 15.0 µg/dL or greater, whereas in 1989, 21.3% of the children were in this category. Two oral behaviors also changed significantly between 1989 and 1991. In 1989, pica was present in 35.5% of the children; in 1991 this percentage fell to 18.8% ($p=0.004$). In 1989, 46.2% of the children put things in their mouths, compared with 31.7% in 1991 ($p=0.03$).

Table A.17b-1. Distribution of Blood-Lead Concentration (µg/dL) by Age and Sampling Round

	Children Tested in Both 1989 and 1991			All Children Tested in 1991	
Age (y) in 1991	n	1989 Mean PbB	1991 Mean PbB	n	1991 Mean PbB
< 1	0	-	-	2	2.7
35796	8	6.1	5.2	23	5.2
35857	16	12.8	5.7	18	5.4
35920	17	9.8	5.5	23	5.4
35983	22	9.5	4.3	23	4.3
36047	12	9.4	4.9	12	4.9
0-10 (95% CI)	75	9.7 (8.6-10.9)	5.0[a](4.5-5.6)	101	5.0(4.5-5.4)
6 mos- 5 yr (95% CI)	24	9.8 (8.6-11.2)	5.5[a] (4.9-6.3)	NA	NA

[a] Represents a significant change in 1991 from the 1989 values

Conclusions (including caveats). The results of the 1991 survey revealed that the lead-poisoning prevention program reached its main objective, which was to lower the mean blood-lead level of children who lived in the contaminated area to a value that ranged from 5.0 to 8.0 µg/dL. The mean blood-lead concentration of children who were 6 months to 10 years of age dropped from 9.2 µg/dL to 5.0 µg/dL in 1991. Similar geometric mean blood lead levels were observed in children who had lived in the area in 1989 and in new residents 6 months to 10 years of age. The 1989 and 1991 surveys were conducted in late summer/early fall, when blood-lead concentrations are highest. Thus, seasonality of blood-lead concentrations was not a factor in this study.

A.17c. Rouyn-Noranda Soil Abatement Study

Reference. Gangne, D., "Blood Lead Levels after Removal of Contaminated Soil." *Canadian Journal of Public Health*. 85(3):163-166.

Pertinent Study Objectives. This study assesses the evolution of blood-lead concentrations in the Notre-Dame district of Rouyn-Noranda, site of an active copper smelter, following the implementation of reduced air emissions since 1979, and soil removal and replacement in 1990-1991. This study compares the results of three blood-lead screenings: 1979, 1989, 1991.

Sampled Population. In 1979, 29 children were sampled within the Notre-Dame district. In 1989, 117 of 124 (94%) two to five year old children residing in the district participated in the study. In 1991, 87 of 96 (90%) one to five year old children in the district participated. All participants had lived in the district for at least six months.

Intervention Strategy. All residential lots with greater than 500 mg/kg (ppm) soil lead were abated. Soil abatement consisted of removal of the first 10 cm of yard soil and replacement with uncontaminated soil. Yard areas were covered with grass and parking areas with gravel. Soil abatement was completed in August 1991 at an average cost of $5000/lot, including landscaping. In all, 80% of the 710 residential lots in the district were abated.

Measurements Taken. Blood samples were taken in September 1979, 1989, 1991. Blood samples were analyzed by atomic absorption (deuterium corrected) and zinc protoporphyrins by hematoflourometer. Socioeconomic characteristics of families were obtained by questionnaire. Atmospheric dust was collected in plastic cylinder gauges suspended 3 m from the ground. Dust samples were analyzed in a water-methanol mixture by atomic absorption on a monthly basis.

Study Design. The Notre-Dame district is located within 1 km of a 2,500 ton/day copper smelter. The district contains approximately 700 residential lots. This study compared the results of the three screening campaigns (1979, 1989, and 1991) and provided an overview of upcoming activities in 1995. All three screenings took place in mid-September and focused on children between two and five years of age (except in 1991 when one-year-olds were also included), living in the district of concern for at least six months. All three screening campaigns were based on a common strategy: recruiting children living in the affected district, taking blood samples, and documenting certain socioeconomic characteristics of their families through a questionnaire. The main outcome measurement was blood-lead concentrations.

No organized effort was made to reduce soil contamination from 1979 to 1989. Between 1979 and 1989, the stack emissions had been lowered by 50% and lead was banned from gasoline during this time period. In 1990-91, it was decided that all residential lots having more than 500 mg/kg (ppm) of lead would be decontaminated and that from 1992 to 1995 air lead levels would be lowered.

Study Results. From 1979 to 1989 the district geometric mean blood lead concentration dropped from 21 µg/dL to 10 µg/dL in two to five year old children (Table A.17c-1). However, in 1989 50% of all children still had PbB greater than 10 µg/dL. In 1991, the geometric mean dropped to 7.2 µg/dL for one to five year old children. Also in 1991, 75% of children had PbBs which were less than 10 µg/dL, and none had PbBs greater than 20 µg/dL.

Table A.17c-1. Distribution of Blood-Lead Concentrations (µg/dL) in 1979, 1989, and 1991

Year	N	Geometric Mean, (PbB, µg/dL)	Median	95th Percentile (µg/dL)	Intervention
1979	29	21	22.3	29	Lead in gas elimination
1989	117	10	10.4	20	Stack lead reduction
1991	89	7.3	7.2	14.7	Soil (>500 ppm) removal

Conclusions (including caveats). This study showed that it was possible to decrease significantly PbB in previously exposed children by soil decontamination in the Notre-Dame district of Rouyn-Noranda in Quebec, Canada. This reduction in PbB was not as effective as that achieved in at St-Jean-sur-Richelieu during the same time period. However, in St-Jean-sur-Richelieu, the lead hazard source was eliminated after decontamination. In Rouyn-Noranda, atmospheric lead emission from the smelter continued during the time of the study.

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APPENDIX B

SUMMARY OF BLOOD-LEAD CONCENTRATION, BODY-LEAD BURDEN, AND ENVIRONMENTAL MEDIA RESULTS FOR IDENTIFIED LEAD HAZARD INTERVENTION STUDIES

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Table B-1. 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%
New York Paint Abatement	"Low" HES Score (≤37)	40	25	40	6	-16%	--	--	nc
	"High" HES Score (>37)	39	31	39	6	-26%	--	--	nc
Central Massachusetts Retrospective	Abated	132	26	132	3-52 weeks	-18%	--	--	nc
Baltimore 3-City Soil Abatement [(2)]	Treatment	--	9.44	--	3	-11%	--	8-15	-1%
	Control	--	9.28	--	3	-18%	--	9-15	-10%
Cincinnati 3-City Soil Abatement [(3)]	Area A	50	10.42	50	3	-18%	27	23-24	+7%
	Area B	77	13.05	77	3	-14%	48	23-24	-16%
	Area C	46	9.47	47	3	-27%	26	23-24	-17%
Toronto Soil and Dust	South Riverdale Study	154	10.9	--	--	nc	110	60	-64%
1990 St. Louis [(1)] Retrospective	Abated	--	na	–	–	nc	49	10-14	-23%
	Unabated	--	na	–	–	nc	22	10-14	-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%

Table B-1. 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 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%
Rouyn-Noranda Soil	Study	117	10	--	--	nc	89	24	-27%
St. Jean-Sur-Richelieu Soil and Dust	Study	75	9.7	--	--	nc	75	24	-48%
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%
Leadville/Lake County Educational Intervention [2]	Community	66	5.02	--	--	--	66	12	-10%
	Intervention	8	11.4	--	--	--	8	12	-19%
Trail Dust Intervention [2]	Treatment	55	11.9	--	--	--	55	12	-8%
	Control	56	11.3	--	--	--	56	12	-6%
NJ's Children's Lead Exposure and Reduction Dust Intervention	Lead	46	12.4	--	--	--	46	12	-17%
	Accident	53	11.6	--	--	--	53	12	+1%
Boston Interim Dust Intervention	Automatic Intervention	8	17.5	8	6	-48%	--	--	--
	Randomized Intervention	11	17.6	11	6	-35%	--	--	--
	Randomized Comparison	13	16.3	13	6	-36%	--	--	--
Rochester Educational Intervention [4]	Intervention	52	6.85	--	--	--	52	7	-1%
	Control	43	6.1	--	--	--	43	7	-14%

Table B-1. 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
Baltimore R&M Paint Abatement [5] Initial PbB < 20	R&M Level I	34	8.8	26	6	+1%	15	24	-20%
	R&M Level II	27	10.5	21	6	+10%	12	24	-10%
	R&M Level III	29	11.4	25	6	+6%	17	24	-16%
	Previously Paint-Abated	20	11.8	18	6	+19	13	24	-14%
	Modern Urban	20	3.4	16	6	+15%	15	24	-6%
Baltimore R&M Paint Abatement [5] Initial PbB ≥ 20	R&M Level I	1	20	1	6	-17%	0	24	
	R&M Level II	7	28.3	7	6	-33%	6	24	-49%
	R&M Level III	8	29.5	6	6	-29%	6	24	-47%
	Previously Paint-Abated	3	29.1	3	6	-22%	3	24	-42%
	Modern Urban	0		0	6		0	24	
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

[1] Follow-up measurements were collected 10-14 months after diagnosis of elevated blood-lead levels (and ensuing educational intervention). The timing of the abatements was not available.
[2] Geometric mean blood-lead concentration provided
[3] Follow-up figures based on data from subset of children participating in both follow-up and initial study periods. Initial mean based on data from subset of children participating in both 3-month post-intervention follow-up and baseline study periods.
[4] Median blood-lead concentration provided.
[5] Model predicted blood-lead concentration provided.
nc Measurements were not collected during these time intervals.
na Insufficient information is available in the literature to allow determination of these values.

Table B-2. 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 B-3. 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	µg/ft²	53	280	251	1.07	271	1440	1.1	48 Hrs	234	316	1.07	6
		Window Sill Dust	µg/ft²	53	249	1338	1.1	246	3595	1.12	48 Hrs	199	1542	1.13	6
		Window Well Dust	µg/ft²	53	150	15496	1.17	139	14353	1.14	48 Hrs	100	12468	1.19	6
	"Modified" Paint Abatement	Floor Dust	µg/ft²	18	82	288	1.18	50	650	1.21	48 Hrs	57	316	1.16	6
		Window Sill Dust	µg/ft²	18	95	1802	1.16	64	604	1.18	48 Hrs	66	1644	1.21	6
		Window Well Dust	µg/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	µg/ft²	6	70	520	1.17	70	130	1.18	[1]	63	56	1.17	6
		Window Sill Dust	µg/ft²	6	34	4608	1.26	35	325	1.36	[1]	31	409	1.32	6
		Window Well Dust	µg/ft²	6	28	29422	1.31	31	938	1.33	[1]	24	1003	1.42	6
Baltimore "Experimental" Paint Abatement Study	"Experimental" 1.5-3.5 Years	Floor Dust	µg/ft²	13	42	254	--	47	13.9	--	[1]	71	40.9	--	18-42
		Window Sill Dust	µg/ft²	13	53	1041	--	54	13	--	[1]	59	103	--	18-42
		Window Well Dust	µg/ft²	13	31	14214	--	41	34.4	--	[1]	49	600	--	18-42
Baltimore[2] 3-City Soil Abatement	Treatment	Comp. Soil	ppm	57	57	503.6	268.2	57	33.6	34.9	1 week	--	--	--	--
		Comp. Interior Dust	µg/ft²	33	33	165.8	217.5	33	90.7	86.3	1 week	--	--	--	--
	Control	Comp. Soil	ppm	147	147	501.3	312.1	--	--	--	--	--	--	--	--
		Comp. Interior Dust	µg/ft²	40	40	162.7	294.4	40	103	137.5	1 week				

Table B-3. 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.
Cincinnati 3-City Soil Abatement	Area A	Entry	µg/ft²	32	32	42.9	--	32	25.9	--	3 mo.	18	24.2	--	24 mo.
		Floor	µg/ft²	32	32	17.5	--	32	7.1	--	3 mo.	25	6.5	--	15 mo.
		Windows	µg/ft²	32	32	97.3	--	32	50.3	--	3 mo.	25	495.2	--	15 mo.
		Exterior Dust-Lead	ppm	217	217	1314	--	309	1707	--	3 mo.	167	1184	--	15 mo.
		Top 2 cm Soil Core Composite	ppm	195	195	200	--	160	54	--	9 mo.	159	58.8	--	30 mo.
	Area B	Entry	µg/ft²	65	65	22.8	--	63	5.2	--	3 mo.	32	28	--	24 mo.
		Floor	µg/ft²	66	66	12.8	--	63	2.4	--	3 mo.	32	4.6	--	15 mo.
		Windows	µg/ft²	63	63	276.9	--	63	55	--	3 mo.	37	909.5	--	15 mo.
		Exterior Dust-Lead	ppm	304	304	1905	--	--	1793	--	3 mo.	305	1954	--	15 mo.
		Top 2 cm Soil Core Composite	ppm	230	230	103	--	372	148	--	9 mo.	--	59.5	--	30 mo.
	Area C	Entry	µg/ft²	42	42	13.9	--	38	9.8	--	3 mo.	22	41	--	24 mo.
		Floor	µg/ft²	42	42	4.3	--	38	3.2	--	3 mo.	22	2.8	--	15 mo.
		Windows	µg/ft²	42	42	172.2	--	39	115	--	3 mo.	22	727.4	--	15 mo.
		Exterior Dust-Lead	ppm	186	186	586	--		520	--	3 mo.	--	581	--	15 mo.
		Top 2 cm Soil Core Composite	ppm	232	232	140	--	--	163	--	9 mo.	--	161	--	30 mo.

Table B-3. 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.
Boston[3] 3-City Soil Abatement Project	Study	Soil	µg/ft²	34	35	2206	1123	35	141	299	10	34	160	115	20
		Floor Dust	µg/ft²	21	21	6.6	5	14	0.8	3.2	10	11	1.8	2.1	20
		Window Well Dust	µg/ft²	19	19	99.5	13.3	15	248.3	7	10	11	271.2	3.8	20
	Comparison A	Soil	µg/ft²	31	31	2358	1203	32	171	172	9				
		Floor Dust	µg/ft²	22	22	2.5	2.7	15	2.7	2.6	10				
		Window Well Dust	µg/ft²	22	22	244.9	5.4	15	133.1	8.5	10				
	Comparison B	Soil	µg/ft²	26	26	2299	1129	26	180	127	9	26	180	127	9
		Floor Dust	µg/ft²	22	22	2.3	4.2	12	2.5	2.5	10				
		Window Well Dust	µg/ft²	21	21	185.5	5.8	12	321.1	9.4	10				
Minneapolis[4] Dust Intervention	Treatment	Ext. Soil Foundation	ppm	12	12	795	--	12	795	--	4.5 mo.	--	--	--	--
		Ext. Soil Mid-Yard	ppm	12	12	272	--	12	70		4.5 mo.	--	--	--	--
		Ext. Soil Street-Side	ppm	10	10	255	--	10	214	--	4.5 mo.	--	--	--	--
		Ext. Dust Foundation	ppm	12	12	320.8	--	12	72.1	--	4.5 mo.	--	--	--	--
		Ext. Dust Mid-Yard	ppm	12	12	109.8	--	12	28	--	4.5 mo.	--	--	--	--
		Ext. Dust Street-Side	ppm	10	10	103.3	--	10	86.1	--	4.5 mo.	--	--	--	–

Table B-3. 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.
Minneapolis[4] Dust Intervention (Cont'd)	Control	Ext. Soil Foundation	ppm	10	10	561	--								
		Ext. Soil Mid-Yard	ppm	10	10	108	--								
		Ext. Soil Street-Side	ppm	10	10	153	--								
		Ext. Dust Foundation	ppm	10	10	226	--								
		Ext. Dust Mid-Yard	ppm	10	10	43.1	--								
		Ext. Dust Street-Side	ppm	10	10	61.4	--								
Paris, France Paint Abatement	Study	Floor Dust	$\mu g/ft^2$	24	24	83.6		24	49.7		1-2 mo.	24	38.2		3-6 mo.
Baltimore Follow-Up Paint	Study	Floor Dust	$\mu g/ft^2$					22	16		immed.	22	23		19 mo.
		Window Sill Dust	$\mu g/ft^2$					19	31		immed.	19	79		19 mo.
		Window Well Dust	$\mu g/ft^2$					15	35		immed.	15	347		19 mo.
Trail Dust Intervention	Control	Carpet Dust Lead	$\mu g/ft^2$	55	55	25.1	--	55	25.1	--	6 mo.	55	21.4	--	12 mo.
	Treatment	Carpet Dust Lead	$\mu g/ft^2$	56	56	52	--	56	34.4	--	6 mo.	56	33.4	--	12 mo.

Table B-3. 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.
New Jersey CLEARS Dust	Lead	Floor Dust	µg/ft²	42	42	22		40	15		12 mo.				
		Sill Dust	µg/ft²	39	39	75		36	24		12 mo.				
		Carpet/ Vacuum Dust	µg/ft²	27	27	469		22	150		12 mo.				
	Accident	Floor Dust	µg/ft²	42	42	26		45	19		12 mo.				
		Sill Dust	µg/ft²	40	40	61		40	48		12 mo.				
		Carpet/ Vacuum Dust	µg/ft²	28	28	466		27	214		12 mo.				
Baltimore R&M Paint Abatement	R&M Level I	Floor Dust	µg/ft²	52	52	205		53	94		12 mo.	43	43	58	24 mo.
		Sill Dust	µg/ft²	50	50	4305		49	470		12 mo.	40	40	460	24 mo.
		Well Dust	µg/ft²	43	43	156019		45	16698		12 mo.	35	35	9828	24 mo.
		Soil Lead	µg/g	5	5	1355		6	1173		6 mo.	6	1161		18 mo.
	R&M Level II	Floor Dust	µg/ft²	46	46	585		46	76		12 mo.	44	44	59	24 mo.
		Sill Dust	µg/ft²	46	46	6020		46	237		12 mo.	44	44	195	24 mo.
		Well Dust	µg/ft²	45	45	203916		46	2587		12 mo.	42	42	2122	24 mo.
		Soil Lead	µg/g	5	5	1755		6	1101		6 mo.	4	1844		18 mo.
	R&M Level III	Floor Dust	µg/ft²	54	54	3052		54	50		12 mo.	53	53	53	24 mo.
		Sill Dust	µg/ft²	54	54	14438		54	29		12 mo.	54	54	26	24 mo.
		Well Dust	µg/ft²	54	54	300594		54	220		12 mo.	53	53	164	24 mo.
		Soil Lead	µg/g	2	2	1491		4	946		6 mo.	3	710		18 mo.
	Previously Abated	Floor Dust	µg/ft²	32	32	118		28	77		12 mo.	26	26	48	24 mo.
		Sill Dust	µg/ft²	31	31	145		28	75		12 mo.	26	26	35	24 mo.
		Well Dust	µg/ft²	31	31	1816		28	1164		12 mo.	26	26	938	24 mo.
		Soil Lead	µg/g	2	2	2192		2	669		6 mo.	3	529		18 mo.
	Modern Urban	Floor Dust	µg/ft²	33	33	15		31	8		12 mo.	29	29	5	24 mo.
		Sill Dust	µg/ft²	31	31	11		30	9		12 mo.	28	28	6	24 mo.
		Well Dust	µg/ft²	30	30	347		30	208		12 mo.	28	28	154	24 mo.
		Soil Lead	µg/g	10	10	61		10	67		6 mo.	10	69		18 mo.

Table B-3. 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.
Boston Interim Dust	Automatic Intervention	Floor Dust	µg/ft²	10	10	21.5		10	16.1		6 mo.				
		Sill Dust	µg/ft²	10	10	344		10	108		6 mo.				
		Well Dust	µg/ft²	10	10	8955		10	2644		6 mo.				
		Soil Lead	ppm	8	8	2278									
	Randomized Intervention	Floor Dust	µg/ft²	9	9	23.8		9	20.5		6 mo.				
		Sill Dust	µg/ft²	9	9	106		9	61.6		6 mo.				
		Well Dust	µg/ft²	9	9	1119		9	561		6 mo.				
		Soil Lead	ppm	11	11	2112									
	Randomized Comparison	Floor Dust	µg/ft²	13	13	15.8		13	16.4		6 mo.				
		Sill Dust	µg/ft²	13	13	85.6		13	53		6 mo.				
		Well Dust	µg/ft²	8	8	1495		8	1510		6 mo.				
		Soil Lead	ppm	13	13	2465									
HUD Abatement Grant Program	Study	Floor Dust	µg/ft²	256	256	25		256	21		immed.	256	15		6 mo.
		Sill Dust	µg/ft²	245	245	196		245	54		immed.	245	90		6 mo.
		Well Dust	µg/ft²	198	198	13300		198	69		immed.	198	732		6 mo.

(1) Measurements were collected after clean-up procedures were completed.
(2) Arithmetic mean provided in geometric mean column.
(3) Arithmetic means and standard deviations are reported, instead of geometric means and standard deviations.
(4) Median provided in geometric mean column.
A = Non-Carpeted Floor Dust
B = Carpeted Floor Dust
C = Interior Window Sill Dust
D = Window Well Dust

APPENDIX C

SUMMARIES/ABSTRACTS FROM 1995 REPORT

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This material was updated from Section 3.1 of EPA Report 747-R-95-006, July 1995

APPENDIX C

C.1 SUMMARIES OF STUDIES ADDRESSING LEAD ABATEMENT EFFECTIVENESS

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 $\mu g/ft^2$.

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.

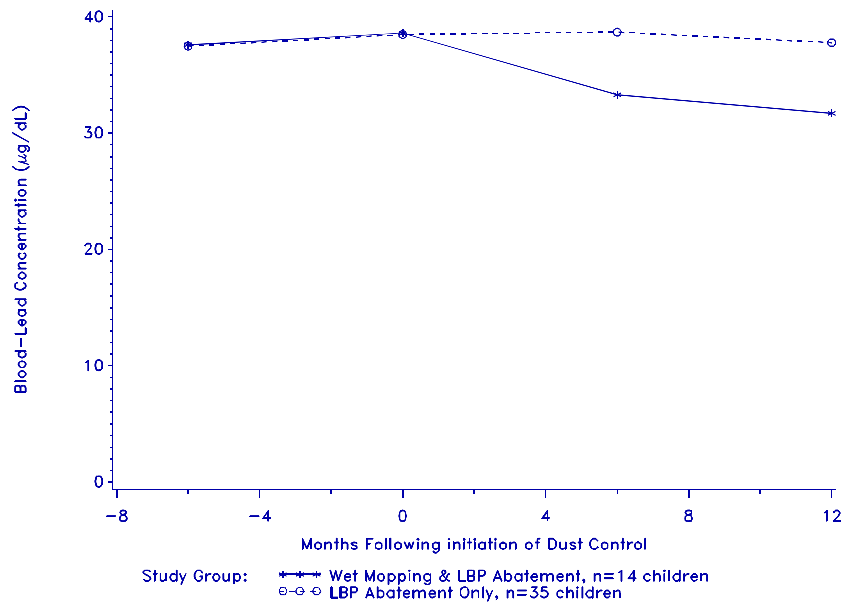

Figure 3-2. Arithmetic mean blood-lead concentration (µg/dL) since abatement by study group (Baltimore Dust Control Study).

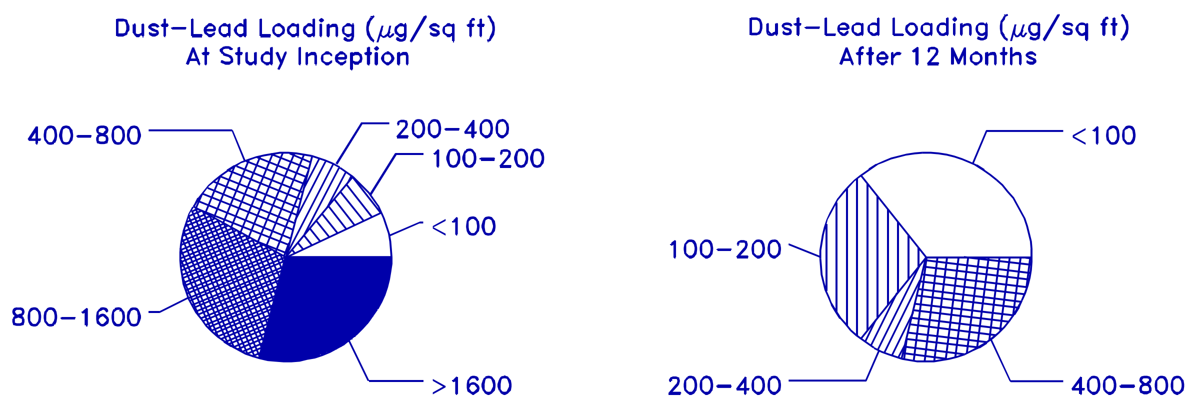

Figure 3-3. Percentage of experimental homes with arithmetic mean dust-lead loadings (µg/ft²) in the defined range (Baltimore Dust Control Study).

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.

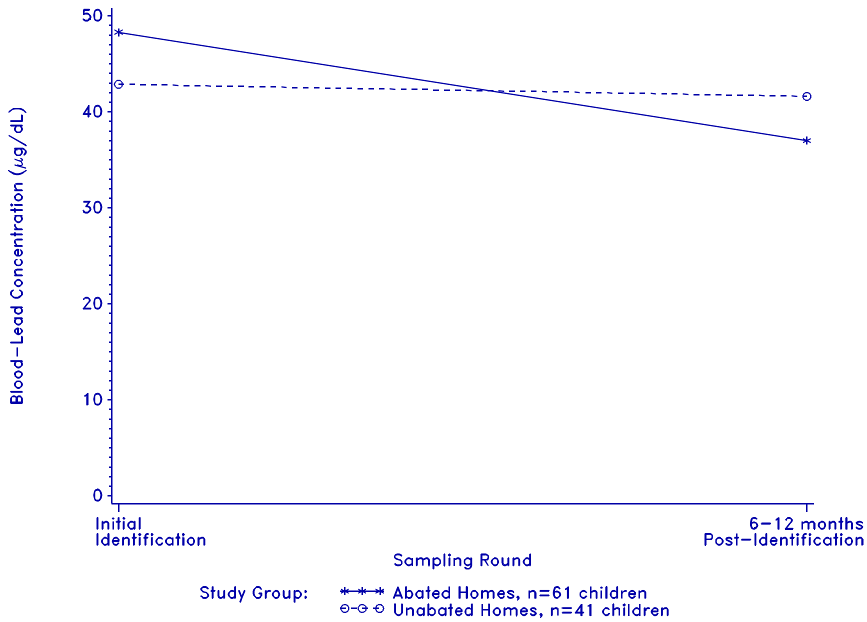

Figure 3-4. Pre- and post-identification arithmetic mean blood-lead concentration (µg/dL) by status of residence abatement (1982 St. Louis Retrospective Paint Abatement Study).

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 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/cm² 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 addition, the modified procedures called for protection of furnishings during abatement and thorough 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 µg/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 µg/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 µg/ft^2 higher than pre-abatement loadings for traditional abatements and 28 µg/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 µg/dL (from 36.88 µg/dL to 43.72 µg/dL) while a rise of only 1.03 µg/dL (from 34.40 µg/dL to 35.43 µg/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 µg/dL) that were not significantly different from their pre-abatement levels (mean, 32.53 µg/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.

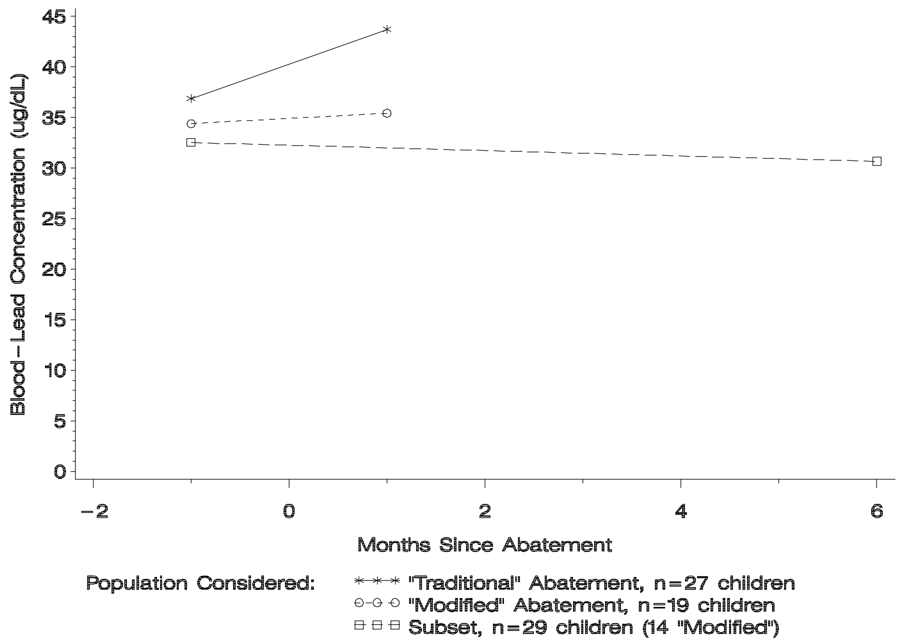

Figure 3-5. Arithmetic mean blood-lead concentration (µg/dL) post-abatement by population considered (Baltimore "Traditional"/"Modified" Paint Abatement Study).

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.

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/cm² 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.

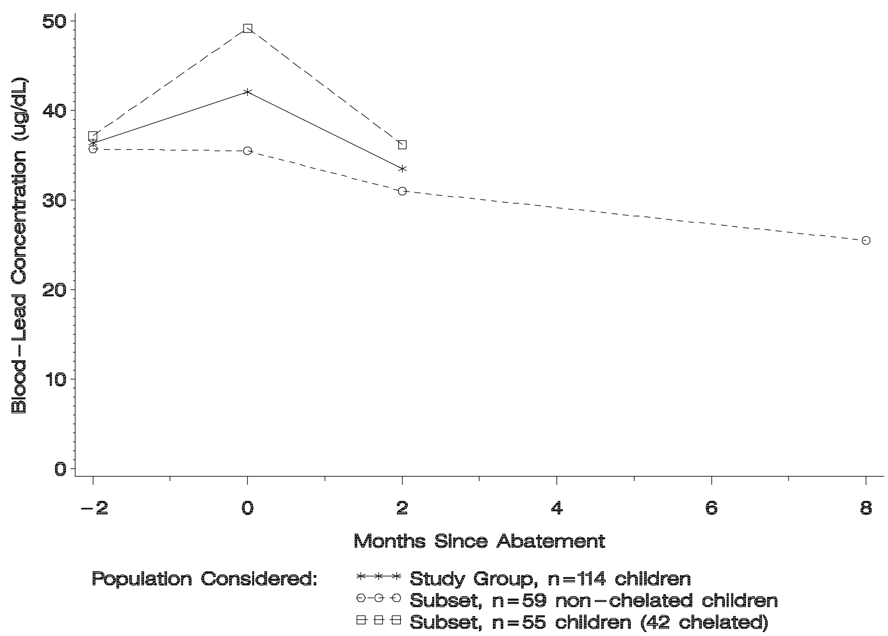

Figure 3-6. Arithmetic mean blood-lead concentration (µg/dL) post-abatement by study population considered (Boston Retrospective Paint Abatement Study).

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 µg/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 µg/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.

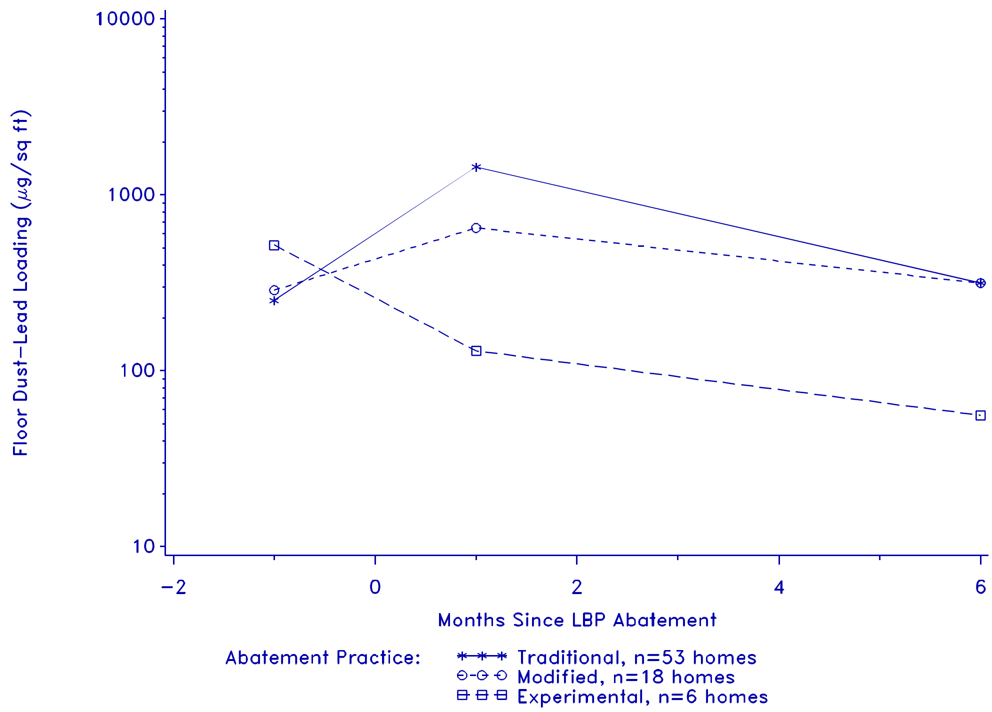

Figure 3-7. **Geometric mean floor dust-lead loading (µg/ft²) post-abatement by abatement practice performed (Baltimore "Traditional"/"Modified" and Experimental Practices Studies).**

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 µg/ft² 1.5 to 3.5 years post-abatement, compared with the pre- and immediately post-abatement levels of 254 µg/ft² and 13.9 µg/ft², respectively. Similarly, the geometric mean window sill dust-lead loading was 103 µg/ft² 1.5 to 3.5 years post-abatement, compared with the pre- and immediately post-abatement levels of 1,041 µg/ft² and 13.0 µg/ft², respectively. Greater reaccumulation was observed for window wells, where the geometric mean dust-lead loading was 600 µg/ft² 1.5 to 3.5 years post-abatement, compared with the pre- and immediately post-abatement levels of 14,214 µg/ft² and 34.4 µg/ft², 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 µg/ft² for floors, 500 µg/ft² for window sills, and

800 µg/ft² 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 residential 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 µg/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/cm² 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 exceeding 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 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.

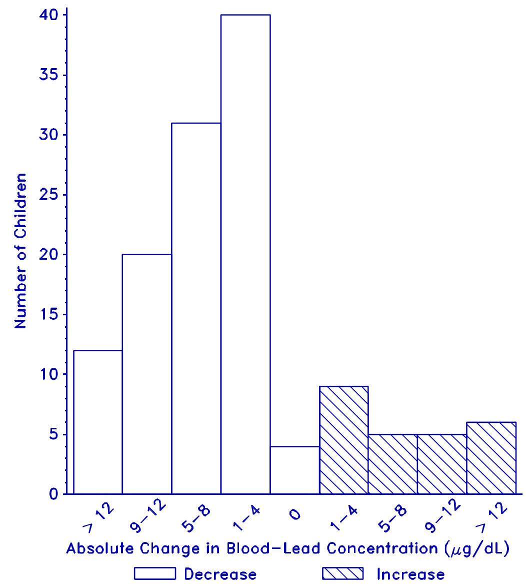

Figure 3-8. Distribution of the absolute change in blood-lead concentrations (Central Massachusetts Retrospective Paint Abatement Study).

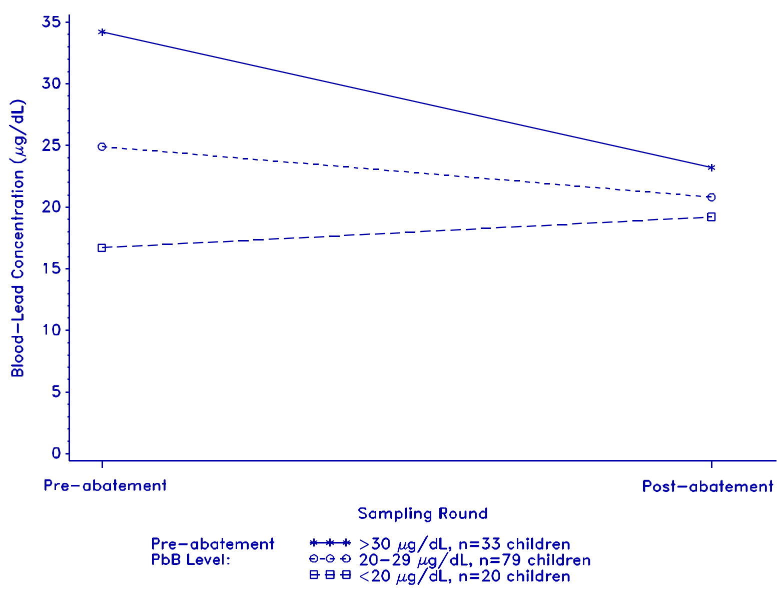

Figure 3-9. Pre-abatement and post-abatement blood-lead concentration by pre-abatement blood-lead level (Central Massachusetts Retrospective Paint Abatement Study).

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 foot 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 1990 St. Louis Retrospective Paint Abatement Study

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 µg/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 185 children selected was 33.6 µg/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 µg/dL. This decline (Figure 3-10) was significantly greater (p=0.07) than the 12% reduction, from 35.1 to 30.9 µg/dL, observed among the 22 children residing in unabated dwellings.

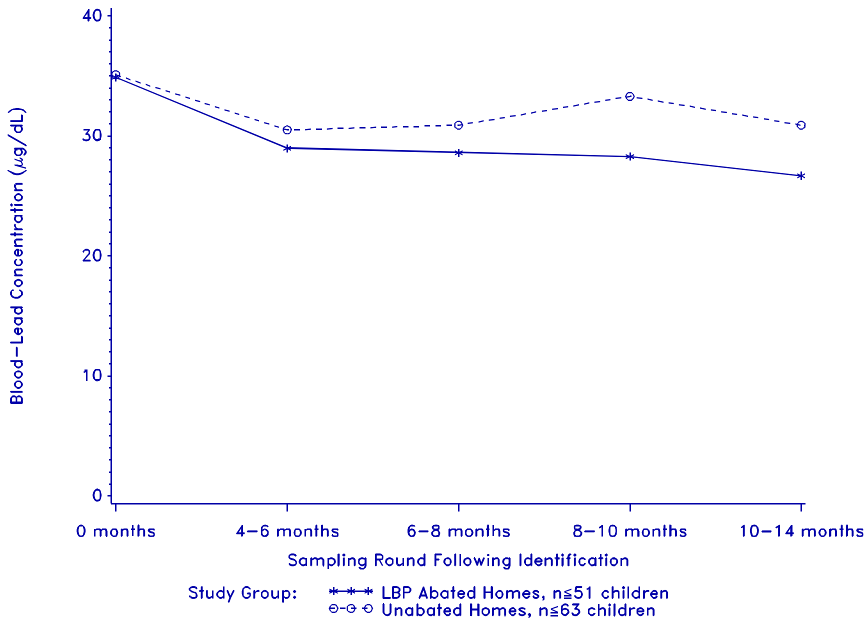

Figure 3-10. Pre- and post-identification arithmetic mean blood-lead concentration (µg/dL) by status of residence abatement (1990 St. Louis Retrospective Paint Abatement Study.)

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

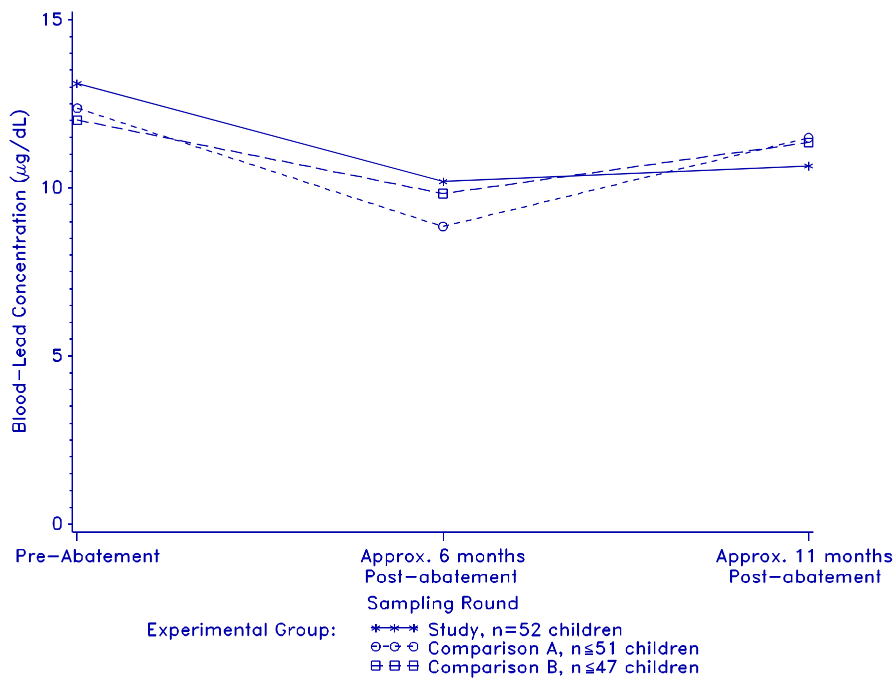

Figure 3-11. Arithmetic mean blood-lead concentration (µg/dL) across sampling rounds and experimental groups, Phase 1 (Boston 3-City Soil Abatement Project).

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. 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.

The decline in median soil-lead concentration among Study group residences immediately post-abatement averaged 1,790 ppm (range: 160 ppm to 5,360 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

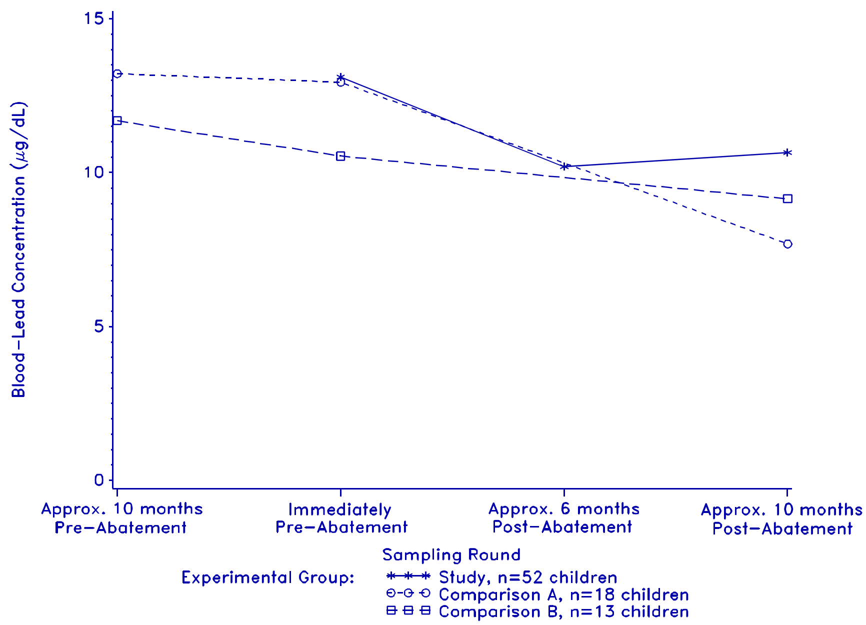

Figure 3-12. Arithmetic mean blood-lead concentration (µg/dL) across sampling rounds and experimental groups, Phase I and II (Boston 3-City Soil Abatement Project).

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.

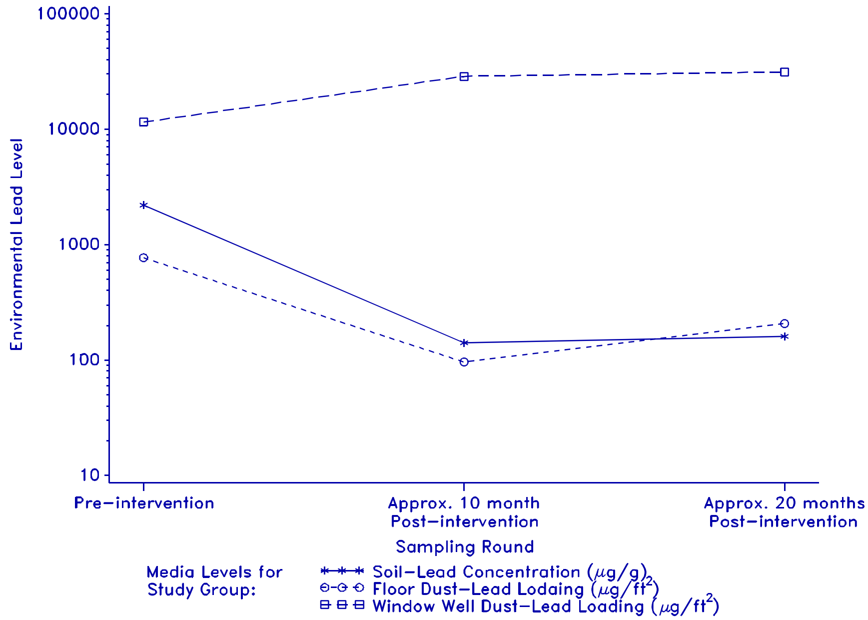

Figure 3-13. Arithmetic mean environmental lead level (for Study Group) across sampling rounds (Boston 3-City Soil Abatement Project).

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 (USEPA, 1995c; 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 <u>HUD Abatement Demonstration (HUD Demo) Study</u>

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/cm². 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/ft² for floors, 500 µg/ft² for window sills, and 800 µg/ft² 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).

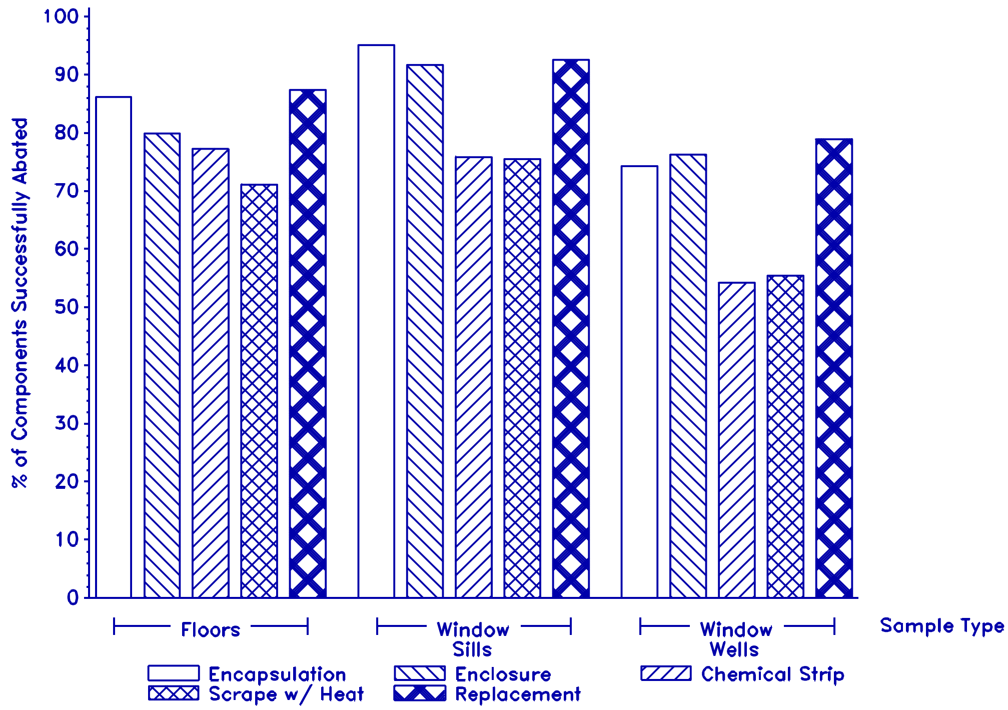

Figure 3-14. Percentage of components successfully abated to HUD Guidelines Standards by abatement method and sampling location (HUD Demo Study).

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.

3.1.11 Denver Comprehensive Abatement Performance (CAP) Study

The 1992 Denver CAP study (USEPA, 1996a, 1996b) 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 Denver 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.

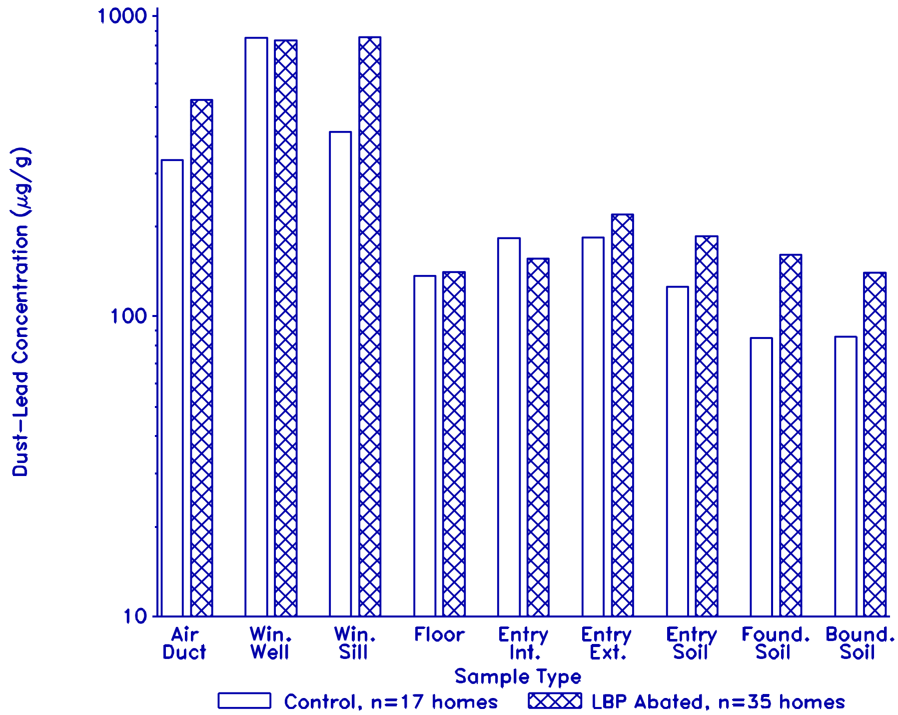

Figure 3-15. Estimated geometric mean dust-lead and soil-lead concentration (µg/g) in typical abated and unabated homes by sampling location (CAP Study).

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/cm² 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).

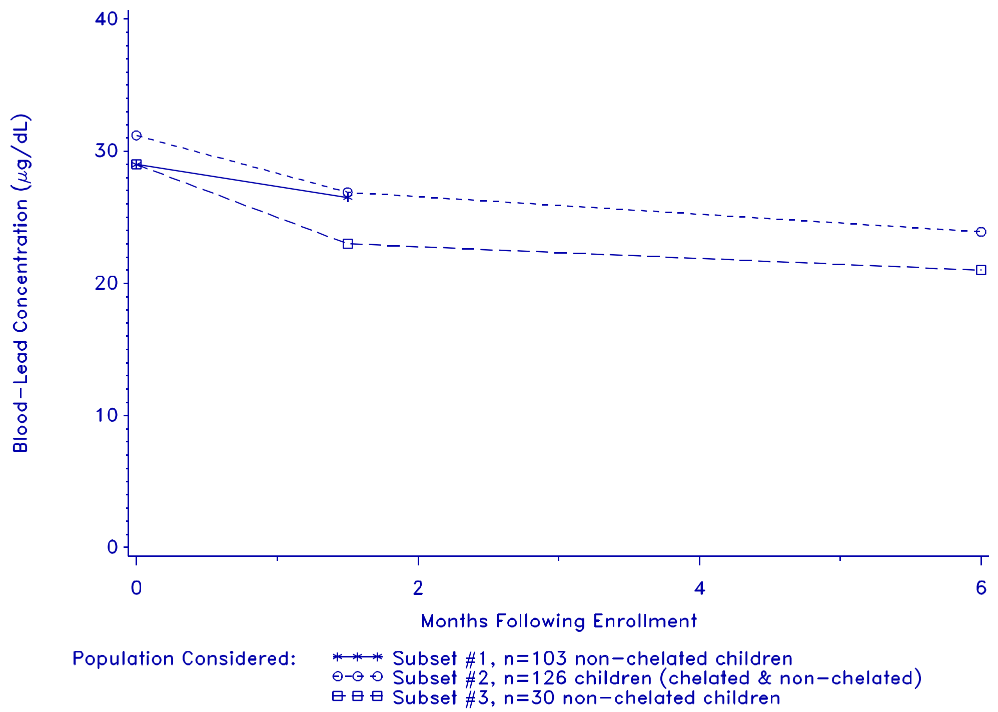

Figure 3-16. Arithmetic mean blood-lead concentration (µg/dL) by population considered (New York Chelation Study).

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 413 children, 7 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, 187 children received an in-home educational visit and had a follow-up blood-lead measure after the in-home visit. The control group of 226 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 187 (82%) children who received an in-home educational visit, compared to 124 of the 226 (55%) children in the control group. The arithmetic mean blood-lead concentration for the Educational Outreach group declined by 21%, from 20 µg/dL to 16 µg/dL, compared to the Control group decline of 6%, from 21 µg/dL to 20 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 4-months and 12-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 years, 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 4-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 4-month post-abatement measurement, but rose again to 9.6 µg/dL by the 12-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.

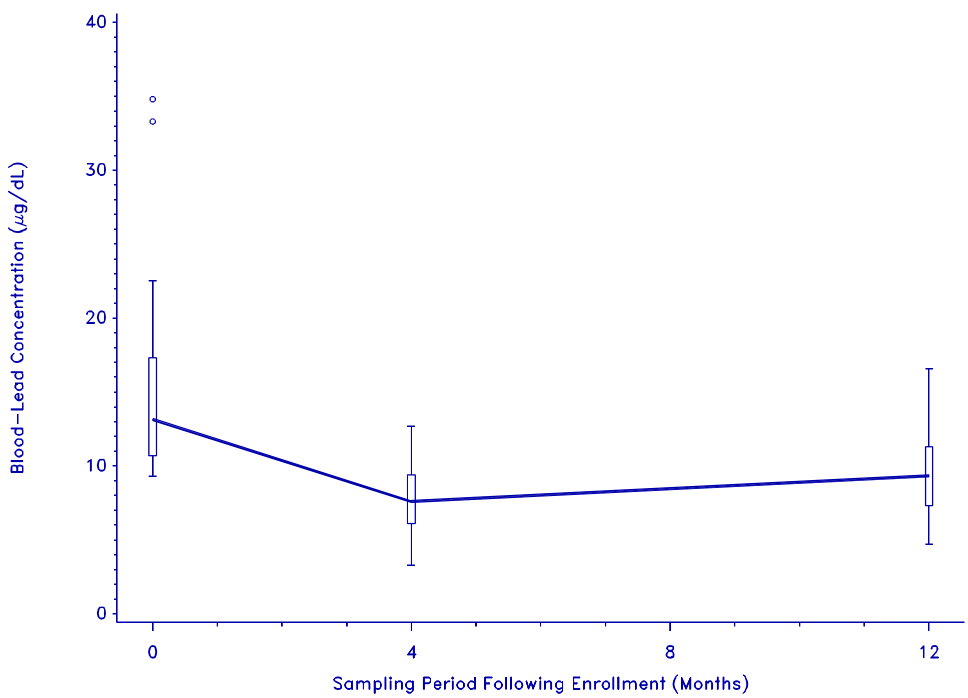

Figure 3-17. Initial and follow-up arithmetic mean blood-lead concentration (µg/dL) (Granite City Educational Intervention Study).

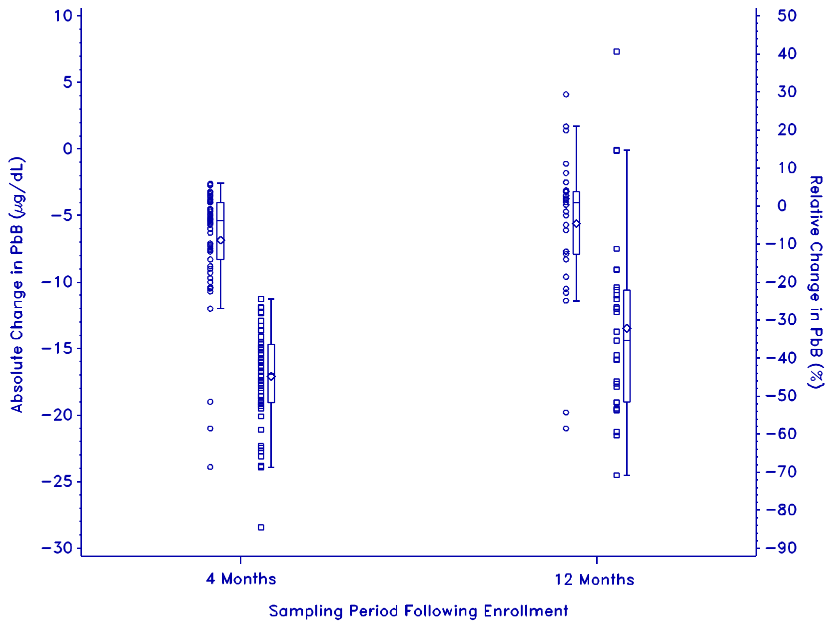

Figure 3-18. Absolute (on left) and percent change in blood-lead concentrations at 4-month and 12-month follow-up (Granite City Educational Intervention Study).

The absolute decrease and percent decrease at the 4-month and 12-month follow-up measures are shown in Figure 3-18 for a subgroup of 24 children under age 6 years 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.

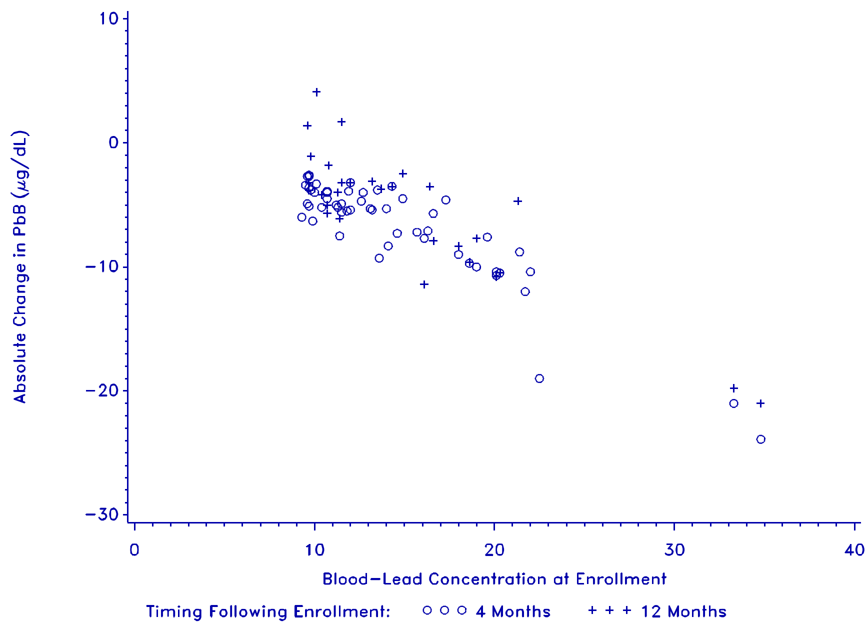

Figure 3-19. Change in blood-lead concentration at 4-month and 12-month follow-up plotted against initial blood-lead concentration (Granite City Educational Intervention Study).

3.1.16 <u>Milwaukee Prospective Educational Intervention Study</u>

This study sought to assess the effectiveness of in-home educational efforts by an educational outreach program established in Milwaukee in 1991 (Schultz et al., 1998). 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.

C.2 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. 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. The children involved in this prospective study were randomly divided into an experimental group of 14 children and a control group of 35 children. Measurements of PbB, FEP and hematocrit were taken approximately every three months during the course of the 12-month study. 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. The primary outcome measures were the blood-lead and FEP levels and the residential dust-lead loadings.

Study Results. 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.

The residential dust-lead loadings obtained before and after the dust-control teams completed their work proved the cleaning to be immediately effective; however, 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/ft²)	Study Inception	After 12 months
<100	1	5
100-200	1	4
200-400	1	1
400-800	3	4
800-1600	4	0
≥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, Missouri.

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. 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. This 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. The blood measures (blood-lead and zinc protoporphyrin) were the primary outcome measures studied.

Study Results. 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 ≥50%	63	126.10	96.06
Compliance ≤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. In this prospective study, serial measurements of lead in interior house dust-lead loading (PbD), and children's blood-lead concentration (PbB) were collected. 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. Dust-lead loadings and blood-lead concentration were the primary outcome measures.

Study Results. 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 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. Post-deleading measures in this retrospective study 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. 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. These blood-lead concentrations were the primary outcome measure.

Study 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). 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 the subset of 59 children who underwent no chelation therapy, 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. This abstract considers the reported results for the two non-overlapping subsets of this prospective 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. 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. The dust-lead loadings from various surfaces in the dwellings were the primary outcome measures.

Study Results. In the first set of analyses (Farfel et al., 1991) examining interior dust-lead over time, 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 (μg/ft²) 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 (μg/ft²) 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 (μg/ft²) 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 m² to μg Pb per ft².

In the second set of analyses (Farfel et al., 1994) examining wipe-dust samples, dust-lead loadings 1.5 to 3.5 years post-abatement were significantly lower from pre- and immediately post-abatement levels (Table A.5-5). Soil-lead concentration which ranged from 209 to 1,962 µg/g (GM=688 µg/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 µg/ft² for floors, 500 µg/ft² for window sills, and 800 µg/ft² 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 (µg/ft²) 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 (µg/ft²) 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 m² to µg Pb per ft².

Table A.5-5. Geometric Mean PbD Loadings (µg/ft²) 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 µg/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., (1995) 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) $\geq$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 determination 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. In this retrospective study, the 132 children's blood-lead concentration measures from at most 6 months prior to the initiation of abatement were compared to the last blood-lead 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 $\geq$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. The primary outcome measure was the blood-lead concentration of the involved children.

Study Results. 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 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.

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

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. Vacuum dust and soil samples were collected, and total dust-lead loadings and fine dust-lead loadings (sieved before analysis) were measured.

Study Design. Low cost dust-control measures were implemented in the forty-two homes that were part of this prospective study and samples were taken from the homes at various times between 1988 and 1990. The 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. The dust-lead loadings were the primary outcome measure.

Study 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/ft²)*	325.2	2415.5	622.5
Fine Dust Loading (mg/ft²)*	74.3	929	157.9
Fine Dust-Lead Loading (µg/ft²)*	28.8	994.1	53.9
Fine Dust-Lead Concentration (ppm)	320	780	430

* Loadings converted from amount Pb per m² to per ft².

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 1,588.6 $\mu g/ft^2$ to 23.2 $\mu g/ft^2$ 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 185 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 $\geq$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 $\geq$0.7 mg/cm²). Children who experienced chelation therapy were excluded.

Intervention Strategy. Interventions entailed the abatement of peeling or chipping lead-based paint (as identified by XRF to have a lead content $\geq$0.7 mg/cm²) 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. Of the 185 children who met the criteria for this retrospective study, 71 had follow-up blood-lead measures 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 concentration was the primary outcome measure.

Study Results. The geometric mean PbB among the 185 children selected was 33.6 µg/dL (range, 25-53 µg/dL). 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 $\geq$35 µg/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 ($\geq$1,000 ppm) in the concentration of lead in residential soil results in a significant decrease ($\geq$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 intervention 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. Each child enrolled in this prospective study 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).

Environmental media and body burden samples were collected at various times surrounding the intervention activities. Soil samples were also collected immediately following soil abatement to confirm its effectiveness. The blood and soil lead concentrations, and dust-lead loadings were the primary outcome measurements.

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

Study Results. 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.9-5). 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).

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

Conclusions (including caveats). These results demonstrate that a reduction of 2,060 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.

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. 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. 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/cm²) of lead.

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. The 172 home abatements in this prospective study occurred between 1989 and 1990. Three of the houses had only pilot abatements performed, while the other 169 were completely abated. 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. 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/ft² for floors, 500 µg/ft² for window sills, and 800 µg/ft² for window wells. Also, core soil samples were collected before and after the abatement procedures were employed. The wipe and soil sample results were the primary outcome measures.

Study Results. Eighty percent of floor wipe clearance samples passed by measuring below the 200 µg/ft² 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 (µg/ft²) 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 µg/ft²	188 (86.2%)	96 (80.0%)	276 (77.3%)	163 (71.2%)	203 (87.5%)	926 (80.1%)
≥ 200 µg/ft²	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 (µg/ft²) 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 µg/ft²	157 (95.2%)	78 (91.8%)	173 (75.9%)	124 (75.6%)	137 (92.6%)	669 (84.7%)
≥ 500 µg/ft²	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 µg/ft² (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 (µg/ft²) 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 µg/ft²	75 (74.3%)	45 (76.3%)	95 (54.3%)	61 (55.5%)	79 (79.0%)	355 (65.1%)
≥ 800 µg/ft²	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%)

An examination of the core soil samples on 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 Denver Comprehensive Abatement Performance (CAP) Study

Reference. U.S. Environmental Protection Agency (1996a), "Comprehensive Abatement Performance Study, Volume I: Summary Report," EPA Report 2130-R-94-013a.

U.S. Environmental Protection Agency (1996b), "Comprehensive Abatement Performance Study, Volume II: Detailed Statistical Results," EPA Report 2130-R-94-013b.

Pertinent Study Objectives. The Denver 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.

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. Of the fifty-two residences selected for this prospective study, thirty-five 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.

Since there is such diversity in 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 Denver 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. These dust-lead and soil sample levels were the primary outcome measures.

Study Results.

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).

- 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 µg/ft², as well as the EPA guidance level (July 14, 1994) of 100 µg/ft². Window sill dust-lead loadings also were below the HUD interim standard of 500 µg/ft². However, window well dust-load loadings in both abated and unabated houses were typically greater than the HUD interim standard of 800 µg/ft².

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 µg/ft²	Lead Conc. µg/g	Dust Load mg/ft²	Lead Load µg/ft²	Lead Conc. µg/g	Dust Load mg/ft²	Lead Load µg/ft²	Lead Conc. µg/g	Dust Load mg/ft²
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	1055	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)	...	86	...	...	1.82^{**}	...	...	0.81	...
Boundary (Soil)	...	86	...	...	1.63^{**}	...	...	1.27	...

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. Blood-lead measurements were taken.

Study Design. Blood-lead results from children in homes where a lead-based paint abatement has taken place were used in this retrospective study. Pre- and post-abatement blood samples were examined, with most of the post abatement samples having been collected 3 to 12 months following abatement. The primary outcome measure is the blood-lead level of the participating children.

Study 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 µg/dL pre-abatement to 26 µg/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, and LXRF tibial bone, EP, blood, and urinary measurements were collected from each child. In addition, an index of cognitive functioning was administered.

Study Design. A total of 201 children were enrolled in this prospective 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.

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 these 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). The environmental measures were collected both at enrollment and six weeks after (the lead-based paint abatement was performed and completed within that time), while the body burden and cognitive function measures were collected from each child at enrollment, 6-7 weeks post-enrollment, and 6 months post-enrollment. The environmental, body burden, and cognitive results were all primary outcome measures.

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).

Study Results. 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 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.

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

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-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.

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.

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. U.S. Environmental Protection Agency (1996c). "Effect of In-Home Educational Intervention on Children's Blood Lead Levels in Milwaukee." EPA Report 747-R-95-009.

Schultz, B.D., Pawel, D., and Murphy, A., (1999) "A Retrospective Examination of In-Home Educational Visits to Reduce Childhood Lead Levels." *Environmental Research* (in press).

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 413 children under 7 years of age, who were identified by the Milwaukee Health Department as having initial blood-lead concentrations between 20-24 µg/dL, and who had a follow-up blood-lead measure and had not moved before the follow-up measure.

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. Out of the 413 children involved in this retrospective study, 187 received an in-home educational visit and had a follow-up blood-lead measure after the in-home visit. The control group of 226 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. The follow-up blood-lead concentrations (PbB) were collected 2-15 months after initial PbB measures. The primary outcome measurement were these blood-lead measures.

Study Results. The arithmetic mean blood-lead concentration for the Educational Outreach group declined by 21 percent, as compared to the Control group decline of 6 percent (Table A.14-1). The difference between these decline is highly statistically significant. Also, blood-lead levels decreased for 154 of the 187 (82%) children in the Educational Outreach group, compared to 124 of the 226 (55%) 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	187	20	4	21
Control	226	21	1	6

Conclusions (including caveats). The results indicate that educational intervention can reduce blood-lead levels, at least for children with blood-lead levels between 20 and 24 μg/dL before intervention. 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., (1995) 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. Initial blood samples were taken from the 490 children involved in this prospective study and when possible, follow-up measures were collected at four months and twelve months after this initial sample. Between the initial and four month samples, the families of these children received extensive counseling in the prevention of lead exposure. The primary outcome measurement was the blood-lead level of the children.

Study 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. The four and twelve month 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

	4 Months			12 Months		
Initial PbB	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., Peppard, P.E., Kanarek, M.S., Murphy, A., White, K.K., and Stroup, C.R., (1998) "A Prospective Study of the Effectiveness of In-Home Educational Visits to Reduce Lead Levels in Children." Draft manuscript.

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 with blood-lead levels greater than 20 µg/dL, had not received a in-home visit in the previous year, and their dwelling had not undergone an abatement within the previous year.

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. Three separate groups of children were examined in this prospective study. 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. The primary outcome measurement was the blood-lead level of the participating children. 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.

Study 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.

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APPENDIX D

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

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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, 1994).

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, 1995). 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 µg/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 <u>TORCH METHODS</u>

B.4.1 <u>Description of Torch Methods</u>

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 µg/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 µg/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 (USEPA, 1993c).

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, 1995) 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; Burgoon, et al, 1993; USEPA 1994a, 1994b).

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.

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APPENDIX E:

REVIEW OF PUBLISHED INFORMATION ON POST-INTERVENTION WIPE DUST-LEAD LOADINGS ON FLOORS AND WINDOW SILLS

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March 12, 1999

DRAFT FINAL REPORT

on

REVIEW OF PUBLISHED INFORMATION ON POST-INTERVENTION WIPE DUST-LEAD LOADINGS ON FLOORS AND WINDOW SILLS

by

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EXECUTIVE SUMMARY

This report summarizes published information on lead loadings (amount of lead per unit surface area) in dust samples collected by wipe techniques, as reported by earlier lead intervention studies. This information is used to evaluate assumptions made on post-intervention dust-lead loadings (40 µg/ft^2 for floors, 100 µg/ft^2 for window sills) within the §403 Risk Analysis.

This report has identified the following seven studies in which some type of paint or dust intervention was performed, dust samples were collected using wipes or some other technique (e.g., BRM vacuum) whose results could be converted to wipe-equivalent dust-lead loadings, and post-intervention dust-lead loadings on floors and/or window sills were reported:

- Baltimore Experimental Paint Abatement Studies
- Baltimore Follow-up Paint Abatement Study
- Baltimore Repair & Maintenance (R&M) Study
- Boston Interim Dust Intervention Study
- Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program ("HUD Grantees")
- Denver Comprehensive Abatement Performance (CAP) Study
- Jersey City Children's Lead Exposure and Reduction (CLEAR) Study

These studies employed a variety of intervention strategies, including single or repeated dust cleanings and interim control or complete abatement of lead-based paint. Dust-lead loadings were measured at varying intervals following intervention. Post-intervention dust-lead loadings were summarized for 19 groups of housing units across these seven studies.

For both floors and window sills, geometric mean and median dust-lead loadings were observed below the post-intervention assumptions established in the §403 Risk Analysis in a majority of the study groups. However, this does not preclude results for individual housing units from being above the assumed levels. Furthermore, the extent to which results for these studies represent the nation's housing stock has not been determined. Results are now presented separately for floors and window sills.

•

POST-INTERVENTION FLOOR DUST-LEAD LOADINGS According to Table ES-1, all but two of the 19 study groups reported geometric mean or median floor dust-lead loadings at or below 41 µg/ft^2, for periods ranging from 6 months to 6 years post-intervention. The other two study groups were from the Baltimore Experimental Paint Abatement Study, where pre-intervention geometric mean dust-lead loadings were much greater (556 µg/ft^2 and 1261 µg/ft^2) than any other study group (at most 58.6 µg/ft^2). Eleven study groups reported geometric mean or median floor dust-lead loadings at or below 21 µg/ft^2 at follow-up periods ranging from 12 months to 2 years. Four of the HUD Grantees study groups reported median floor dust-lead loadings at or below 10 µg/ft^2 at 12 months post-intervention. Median pre-intervention floor dust-lead loadings in these four groups ranged from 9 to 26 µg/ft^2.

In the HUD Grantees evaluation, seven of the eight largest grantees have median floor dust-lead loadings at or below 21 µg/ft^2 at 12 months post-intervention, compared to a median of 14 µg/ft^2 across all grantees. Although pre-intervention floor dust-lead loadings were lower in the HUD Grantees evaluation compared to other studies, these preliminary results suggest that floor dust-lead loadings can be maintained at levels below 40 µg/ft^2 for at least 12 months post-intervention.

Results from the Denver CAP study, the Baltimore Follow-up Paint Abatement study, the Baltimore R&M study, the Boston Interim Dust Intervention study, and the Jersey City CLEARS suggest that geometric mean floor dust-lead loadings of below 40 µg/ft^2 can be observed for up to six years post-intervention.

POST-INTERVENTION WINDOW SILL DUST-LEAD LOADINGS

Summaries of post-intervention window sill dust-lead loadings are presented in Table ES-2 according to housing group. Post-intervention geometric means or medians range from 24 µg/ft^2 to 958 µg/ft^2, which are considerably higher than the summaries for floors. Eleven study groups had geometric mean or median post-intervention window sill dust-lead loadings below 100 µg/ft^2, 6 groups were at or below 51 µg/ft^2, and 3 groups were at or below 41 µg/ft^2.

Table ES-1. Summaries of Pre- and Post-Intervention Floor Dust-Lead Loadings

Study	Study Group	Pre-Intervention Floor Dust-Lead Loadings[1] (μg/ft²)	Post-Intervention Floor Dust-Lead Loadings[1]	
			Time Following Intervention (Months)	Summary Value (μg/ft²)
Baltimore Experimental Paint Abatement Studies[2]	Study 1	1,261	6-9	99
	Study 2	556	1.5 - 3.5 Years	69
Baltimore Follow-up Paint Abatement Study[2]	12-Month Follow-up	NA	10-14	20
	19-Month Follow-up	NA	14-24	36
Baltimore R&M Study[3]	Previously-Abated Units	46	4 - 6 Years	33
	Units Slated for R&M Intervention	59	24	35
Boston Interim Dust Intervention Study[2]	Automatic Intervention	33	6	24
	Randomized Intervention	37	6	31
HUD Grantees[4]	All Grantees	19	12	14
	Baltimore	41	12	41
	Boston	24	12	18
	Massachusetts	24	12	9
	Milwaukee	14	12	10
	Minnesota	18	12	18
	Rhode Island	26	12	6
	Vermont	28	12	21
	Wisconsin	9	12	5
Denver CAP Study[5]	Abated Units	NA	2 Years	21
Jersey City CLEARS[6]	Dust Intervention	22	12	15

[1] Values are geometric means except for the HUD Grantees studies, where values are medians. "NA" indicates not available.
[2] Results are adjusted to reflect total dust-lead loadings by exponentiating the "bioavailable" dust-lead loadings as reported in the study to the 1.1416 power.
[3] Results for the Baltimore R&M Study are converted from BRM dust-lead loadings to wipe-equivalent loadings.
[4] Data collected through September, 1997
[5] Results for the Denver CAP study are converted from CAP cyclone dust-lead loadings to wipe-equivalent loadings.
[6] An alternative (LWW) wipe sampling method was used in the CLEARS study. No adjustments were made to convert the LWW wipe loadings reported in this study to standard wipe loadings.

<u>Note</u>: More details are provided in the main body of the report.

Table ES-2. Summaries of Pre- and Post-Intervention Window Sill Dust-Lead Loadings

Study	Study Group	Pre-Intervention Sill Dust-Lead Loadings[1] (µg/ft²)	Post-Intervention Sill Dust-Lead Loadings[1]	
			Time Following Intervention (Months)	Summary Value (µg/ft²)
Baltimore Experimental Paint Abatement Studies[2]	Study 1	15,215	6-9	958
	Study 2	2,784	1.5 - 3.5 Years	199
Baltimore Follow-up Paint Abatement Study[2]	12-Month Follow-up	NA	10-14	41
	19-Month Follow-up	NA	14-24	147
Baltimore R&M Study[3]	Previously-Abated Units	164	4 - 6 Years	98
	Units Slated for R&M Intervention	778	24	205
Boston Interim Dust Intervention Study[2]	Automatic Intervention	787	6	210
	Randomized Intervention	205	6	110
HUD Grantees[4]	All Grantees	258	12	90
	Baltimore	1,191	12	68
	Boston	174	12	49
	Massachusetts	328	12	50
	Milwaukee	264	12	217
	Minnesota	266	12	77
	Rhode Island	314	12	85
	Vermont	147	12	40
	Wisconsin	150	12	51
Denver CAP Study[5]	Abated Units	NA	2 Years	66
Jersey City CLEARS[6]	Dust Intervention	75	12	24

[1] Values are geometric means except for the HUD Grantees studies, where values are medians. "NA" indicates not available.
[2] Results are adjusted to reflect total dust-lead loadings by exponentiating the "bioavailable" dust-lead loadings as reported in the study to the 1.1416 power.
[3] Results for the Baltimore R&M Study are converted from BRM dust-lead loadings to wipe-equivalent loadings.
[4] Data collected through September, 1997
[5] Results for the Denver CAP study are converted from CAP cyclone dust-lead loadings to wipe-equivalent loadings.
[6] An alternative (LWW) wipe sampling method was used in the CLEARS study. No adjustments were made to convert the LWW wipe loadings reported in this study to standard wipe loadings.

Note: More details are provided in the main body of the report.

All but one of the HUD Grantees study groups (the Milwaukee grantee) had median window sill dust-lead loadings below 100 µg/ft^2 at 12 months post-intervention. In addition, geometric mean window sill dust-lead loadings were below 100 µg/ft^2 for up to two years post-intervention in the Baltimore Follow-up Paint Abatement study, Denver CAP study, and Jersey City CLEARS. However, in the Baltimore R&M study, Baltimore Experimental Paint Abatement studies, and Boston Interim Dust Intervention study, geometric mean dust-lead loadings remained above 100 µg/ft^2 over time. In addition, the 19-month follow-up study group within the Baltimore Follow-up Paint Abatement study and study group #2 of the Baltimore Experimental Paint Abatement studies suggest that geometric mean dust-lead loadings can dip below 100 µg/ft^2 immediately after intervention, but then exceed this level after one year or so.

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1.0 INTRODUCTION

Section 403 of the Toxic Substances Control Act, as amended within the Residential Lead-Based Paint Hazard Reduction Act of 1992 (Title X), requires the U.S. Environmental Protection Agency (EPA) to establish criteria for identifying lead-based paint hazards, including lead-contaminated household dust and residential soil. In June, 1998, EPA completed a risk analysis to provide a scientific foundation for establishing regulatory standards for lead in paint, dust, and soil, in response to §403. EPA used the methods and findings of this risk analysis to issue a proposed rule (40 CFR Part 745, dated 3 June 1998) containing proposed standards for lead-based paint hazards in target housing and child-occupied facilities. The proposed §403 standards were specified as follows:

Environmental Parameter	Proposed §403 Standard for the Parameter
Average floor dust-lead loading	50 µg/ft^2
Average window sill dust-lead loading	250 µg/ft^2
Yard-wide average soil-lead concentration	2,000 ppm
Amount of deteriorated lead-based paint on painted building components	• 10 ft^2 on exterior components with large surface areas • 2 ft^2 on interior components with large surface areas • 10% of total surface area of components with small surface areas

Dust-lead loading standards assume a wipe dust collection technique.

One goal of the §403 risk analysis was to determine how the likelihood of children with blood-lead concentrations exceeding certain thresholds (10 and 20 µg/dL) declines as a result of reducing environmental-lead levels when interventions are performed in response to §403 rules. An empirical model was used in both a pre- and post-intervention setting to predict geometric mean blood-lead concentration as a function of environmental-lead levels, including average dust-lead loadings for floors and window sills. It was assumed that pre-intervention average dust-lead loadings on floors and window sills were reduced when performing the following interventions:

- Dust cleaning (as triggered by exceeding either the floor or window sill dust-lead standards)

- Interior paint abatement
- Soil removal

For each of these interventions, the assumed post-intervention wipe dust-lead loadings are as follows:

- Floors: 40 µg/ft^2 or the pre-intervention value, whichever is smaller
- Window sills: 100 µg/ft^2 or the pre-intervention value, whichever is smaller.

Note that both assumptions are below their respective §403 standards. Post-intervention dust-lead loadings are assumed to hold for four years following a dust cleaning, 20 years following interior paint abatement, and permanently following soil removal.

Since the §403 risk analysis was performed, additional information has been identified which could be used to refine the assumptions on post-intervention wipe dust-lead loadings. This report examines some of that information and summarizes existing data from intervention studies to characterize pre- and post-intervention wipe dust-lead loadings.

2.0 REVIEW OF AVAILABLE INFORMATION

According to Section 6.1.1 of the §403 risk analysis report, the post-intervention dust-lead loadings of 40 µg/ft^2 for floors and 100 µg/ft^2 for window sills were selected based on data from EPA's Comprehensive Abatement Performance (Denver CAP) study and the Baltimore Experimental Paint Abatement study. Justification was as follows:

- Geometric mean <u>vacuum</u> dust-lead loadings from abated units in the Denver CAP study were 29 µg/ft^2 for floors (187 samples) and 92 µg/ft^2 for window sills (78 samples), where the samples were collected approximately two years after paint intervention performed within the HUD Lead-Based Paint Abatement Demonstration.
- Geometric mean <u>wipe</u> dust-lead loadings in the Baltimore Experimental Paint Abatement study were 41 µg/ft^2 for floors and 103 µg/ft^2 for window sills, in 13 housing units approximately 18-42 months after complete paint intervention.

Intervention studies that contain information on pre- and post-intervention dust-lead loadings (assuming either wipe dust collection methods or a method in which the reported loadings can be converted to wipe-equivalent loadings) and that can be used to evaluate the §403 assumptions on post-intervention dust-lead loadings are identified in Table 1. These studies were included in USEPA, 1995a, and USEPA, 1998, which contain summary information on studies available in the scientific literature whose findings could be used to make conclusions on the effectiveness of lead hazard intervention (defined as "any non-medical activity that seeks to prevent a child from being exposed to the lead in his or her surrounding environment"). A summary of key information on study design and conclusions for the studies in Table 1 is found in Appendix A. When comparing dust-lead loading results across the studies in Table 1, the following issues should be considered.

<u>CONVERTING VACUUM DUST-LEAD LOADINGS TO WIPE-EQUIVALENT LOADINGS</u>

Two of the studies in Table 1 used dust collection methods other than the wipe method. The Baltimore R&M study used the BRM vacuum method, while the Denver CAP study

Table 1. Studies Containing Information on Pre-Intervention and Post-Intervention Dust-Lead Loadings on Floors and Window Sills, Where Wipe Collection Methods or a Method Whose Loadings Can Be Converted to Wipe-Equivalents Were Used

Study	Study Duration	Type of Interventions Considered	Type of Wipe Digestion Method	Reference(s)
Baltimore (MD) Dust Control Study	1981	Paint interventions Some units received periodic dust control	Cold HCl	Charney et al., 1983
Baltimore (MD) Experimental Paint Abatement Studies	1986-87 (Study #1) 12/91 - 01/92 (Study #2)	Paint interventions using experimental procedures, with extensive cleanup	Cold HCl	Farfel and Chisolm, 1991 USEPA, 1987 Farfel et al., 1994
Baltimore (MD) Follow-up Paint Abatement Study	01/91 - 06/92	Paint interventions with extensive clean-up	Cold HCl	MDE, 1995
Baltimore (MD) Repair and Maintenance (R&M) Study	1993-95	Various types of R&M paint interventions (including cleanup, prevention of recontamination, and education)	BRM vacuum method was used	USEPA, 1996c USEPA, 1997b USEPA, 1997c
Baltimore (MD) Traditional/Modified Paint Abatement Study	1984-85	“Traditional” and “modified” paint abatements, with some cleanup.	Cold HCl	Farfel and Chisolm, 1990
Boston (MA) Interim Dust Intervention Study	05/93 - 04/95	Intervention groups received paint and/or dust intervention (low-tech). Comparison group received an outreach visit.	Cold HCl	Aschengrau et al., 1998 Mackey et al., 1996
East St. Louis (IL) Educational Intervention Study	1994-95	Educational materials provided, potential lead hazards identified.	Cold HCl (likely)	Copley, 1995

Table 1. Studies Containing Information on Pre-Intervention and Post-Intervention Dust-Lead Loadings on Floors and Window Sills, Where Wipe Collection Methods or a Method Whose Loadings Can Be Converted to Wipe-Equivalents Were Used (Continued)

Study	Study Duration	Type of Interventions Considered	Type of Wipe Digestion Method	Reference(s)
Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program (HUD Grantees) (data collected through August, 1997)	1994 - present	Wide range of interventions to reduce/eliminate lead-based paint hazards.	Heated HNO_3/H_2O_2	NCLSH and UC, 1997 NCLSH and UC, 1998
HUD Abatement Demonstration Program/EPA Comprehensive Abatement Performance (Denver CAP) Study	1989-90 (HUD Demo) 03/92 - 04/92 (Denver CAP Study)	Encapsulation/enclosure Various paint removal methods	Heated HNO_3/H_2O_2 (CAP cyclone was used in the Denver CAP Study)	HUD, 1991 USEPA, 1996a USEPA, 1996b
Jersey City (NJ) Children's Lead Exposure and Reduction (CLEAR) Dust Intervention Study[1]	1992-94	Biweekly dust control assistance and educational sessions	Heated HNO_3/H_2O_2	Adgate et al., 1995 Rhoads et al., 1996 Lioy et al., 1997
Paris Paint Abatement Study	01/90 - 02/92	Paint interventions with dust cleaning	Unspecified	Nedellec et al., 1995
Rochester (NY) Educational Intervention Study	08/93 - 06/94	Intervention group received direction on performing periodic dust control. Control group received educational materials only.	Heated HNO_3/H_2O_2	Lanphear et al., 1995 Lanphear et al., 1996

[1] An alternative (LWW) wipe sampling method was used in the CLEARS study. No adjustments were made to convert the LWW wipe loadings reported in this study to standard wipe loadings.

used a cyclone vacuum specifically developed for the study (CAP cyclone). While post-intervention wipe dust-lead loadings are of interest in this report, these two studies are included in Table 1 as previous efforts allow the vacuum dust-lead loadings to be converted to wipe-equivalent loadings. These conversions were made prior to displaying results from these two studies in this report.

The Baltimore R&M study collected composite dust samples using the BRM vacuum method. The conversion of BRM dust-lead loadings to wipe-equivalent loadings for the Baltimore R&M study was developed within the §403 risk analysis effort (USEPA, 1997a) and takes the following form:

Floors: $\text{Wipe} = (p \times 8.34 \times \text{BRM}^{0.371}) + ((1-p) \times 3.01 \times \text{BRM}^{0.227})$

Window sills: $\text{Wipe} = 14.8 \times \text{BRM}^{0.453}$

where Wipe is the average wipe dust-lead loading, BRM is the average BRM dust-lead loading, and p is the proportion of a composite floor-dust sample obtained from uncarpeted floors. These conversion equations were determined based on side-by-side BRM/wipe dust-lead loading data from four studies.

Dust-lead loadings for samples collected by the Denver CAP study's cyclone vacuum were converted to wipe-equivalent loadings based on the conclusion made within the Denver CAP study that vacuum dust-lead loadings were, on average, 1.38 times larger than wipe dust-lead loadings (page 147 of USEPA, 1996b), regardless of lead level or sampling component. This conclusion was made by fitting a log-linear regression model, using an errors-in-variables approach, on lead loading data for 33 pairs of side-by-side vacuum/wipe dust samples collected within the Denver CAP study. The model predicted vacuum dust-lead loading as a function of wipe dust-lead loading. Therefore, the conversion of vacuum dust-lead loading data from the Denver CAP study (for both floors and window sills) involved dividing each vacuum dust-lead loading by 1.38 to obtain a wipe-equivalent loading. The estimated geometric mean wipe dust-lead loading equals the geometric mean vacuum dust-lead loading, divided by 1.38.

HANDLING DIFFERENCES IN WIPE DIGESTION METHODS

The studies in Table 1 are identified according to the type of wipe digestion method used in the analytical process. Generally, one of two categories of digestion methods was used by each study. The "heated HNO_3/H_2O_2" method, which is the method recommended in EPA's National Lead Laboratory Accreditation Program (NLLAP), allows total lead amounts in the sample to be determined. The "cold HCl" method, documented in Vostal et al., 1974, and used at the Kennedy Krieger Institute in Baltimore, MD, generally allows only "bioavailable" lead amounts to be measured in the sample. Therefore, in order to make wipe dust-lead loadings comparable across all studies in Table 1, it is necessary to adjust the "bioavailable" lead loadings that are reported in the studies that used the "cold HCl" digestion method to reflect total lead amounts. Appendix A of USEPA, 1997a, provided a means by which this adjustment can be made:

$$T = B^{1.1416}$$

where T is the total dust-lead loading, and B is the "bioavailable" dust-lead loading. This adjustment was developed by fitting a log-linear regression model (with no intercept term) on uncarpeted floor dust-lead loading data that were collected in a pilot study (NCLSH, 1993). This pilot study investigated how dust-lead loadings changed across five different sampling and analysis methods.

Differences in measurements between the two wipe digestion methods depend on the sample particle size. Differences related to particle size are probably small and likely even negligible here, as dust is the medium being sampled. This conclusion, however, may not be valid when sampling soil.

In this report, summary statistics for studies labeled in Table 1 as utilizing the "cold HCl" wipe digestion method were calculated on dust-lead loadings that were adjusted by the method described above. This implies taking geometric means calculated on the study data to the 1.1416 power.

CONSIDERING DIFFERENT INTERVENTION METHODS ACROSS STUDIES

As seen in the second column of Table 1, the studies utilized different intervention approaches. The HUD Grantees evaluation program is the most widely-encompassing of the studies, containing dust-lead loading data at up to 12 months post-intervention for floors and window sills in over 500 housing units as measured by 14 Grantees across the country. Therefore, the impact of intervention activities on dust-lead loading will likely vary considerably across these studies. Furthermore, caution should be used in considering the results of certain studies, such as the educational intervention studies, when the aim is to evaluate the effect of performing highly-intensive dust and paint abatements on dust-lead loading.

3.0 RESULTS

For eight studies in Table 1 that measured and documented post-intervention dust-lead loadings and which considered paint and/or dust interventions (i.e., not just educational interventions), Tables 2 and 3 provide summaries of the measured dust-lead loadings from these studies, both prior to intervention (if available) and at specified time points following the interventions, for floors and window sills, respectively. Summaries are presented according to study group within each study. These tables contain geometric mean dust-lead loadings for all studies but the HUD Grantees evaluation, whose references provided only median dust-lead loadings. Note that not all studies in these tables provided information on pre-intervention dust-lead loadings. Also, as discussed in the previous chapter, the measured dust-lead loadings in the Baltimore R&M study and the Denver CAP study have been converted from vacuum to wipe-equivalent loadings, and dust-lead loadings in studies using the "cold HCl" wipe digestion method have been adjusted to reflect total lead loadings, prior to preparing the summaries in Tables 2 and 3.

More detailed dust-lead loading summaries are provided in the tables in Appendix B. These tables include the information in Tables 2 and 3, along with sample sizes associated with the summaries, 95% confidence intervals for selected estimates, and reported differences in dust-lead loadings from pre-intervention which were measured in the Paris Paint Abatement study and the two educational intervention studies in Rochester and East St. Louis.

FLOOR DUST-LEAD LOADINGS

Table 2 contains post-intervention floor dust-lead loading summaries for 24 study groups, including two control groups from the Baltimore R&M study and a total of nine groups from the HUD Grantees evaluation. The Baltimore Traditional/Modified study was included in the table for historical perspective. The abatement and clean-up methods employed in this study are not representative of modern practices. Thus, this study was not considered in the discussion that follows.

Figure 1 presents the post-intervention dust-lead loadings for 18 study groups relative to the post-intervention dust-lead loading assumed in the §403 Risk Analysis. The 18 study groups include 9 study groups from the HUD Grantees Evaluation, the 7 study groups from the Baltimore Follow-Up Paint Abatement, Boston Interim Dust Intervention, Denver CAP, and Jersey City CLEARS studies, and the Previously Abated and the R&M Intervention groups from the Baltimore R&M study. The interventions conducted within these study groups were considered representative of those that might be prompted in response to §403 standards. Because the length of the follow-up period was much longer for the Baltimore R&M Previously Abated study group, the results for this group were plotted relative to the time since enrollment in the R&M study. As seen in Figure 1, the HUD Grantee evaluation groups tended to have post-intervention floor dust-lead loadings below 20 µg/ft^2 up to 12 months post intervention, while other study groups tended to be between 20 and 40 µg/ft^2.

Sixteen study groups in Table 2 contain information on dust-lead loading measurements immediately after intervention, excluding the Baltimore Traditional/Modified study. Of these 16 groups, 10 had geometric mean or median dust-lead loadings ranging from 7-24 µg/ft^2 immediately after intervention. Eight of these 10 groups were from the HUD Grantees evaluation, where pre-intervention median dust-lead loadings were no higher than 41 µg/ft^2. Six of the 16 groups had geometric mean or median dust-lead loadings above 40 µg/ft^2 immediately after intervention.

Among the nine study groups in the HUD Grantees evaluation, seven groups had median dust-lead loadings that remained constant or steadily declined to below 20 µg/ft^2 for up to 12 months post-intervention. The other two study groups had median loadings increase to approximately pre-intervention levels over this 12-month period. In addition, the Denver CAP study, the Baltimore Follow-up Paint Abatement study, the Baltimore R&M study, and Boston Interim Dust Intervention study, and the CLEARS suggest that geometric mean dust-lead loadings of below 40 µg/ft^2 can be observed for up to two years post-intervention. Data from the Previously Abated group in the Baltimore R&M study suggest that geometric mean dust-lead loadings of below 40 µg/ft^2 can be observed for 4 - 6 years post-intervention. Only in study #1 of the Baltimore Experimental Paint Abatement studies did geometric mean dust-lead loadings exceed 40 µg/ft^2 at approximately six months post-intervention; however, pre-intervention levels were higher than in the other studies.

Eleven study groups reported geometric mean or median floor dust-lead loadings at or below 21 µg/ft^2 at follow-up periods ranging from 12 months to 2 years. Four of the HUD Grantees study groups reported median floor dust-lead loadings at or below 10 µg/ft^2 at 12 months post-intervention. Median pre-intervention floor dust-lead loadings in these four groups ranged from 9 to 26 µg/ft^2.

WINDOW SILL DUST-LEAD LOADINGS

The same 24 study groups represented in Table 2 also are included in Table 3, where post-intervention window sill dust-lead loading summaries are presented. Results in Table 3 indicate that post-intervention window sill dust-lead loadings are generally higher than those for floors. The post-intervention geometric means (or medians) range from 18 µg/ft^2 to 958 µg/ft^2, excluding the Baltimore Traditional/Modified study, as before.

Figure 2 presents the post-intervention dust-lead loadings for 18 study groups relative to the post-intervention dust-lead loading assumed in the §403 Risk Analysis. The 18 study groups were the same as those included in Figure 1. As seen in Figure 2, the HUD Grantee Evaluation groups tended to have post-intervention window sill dust-lead loadings below 100 µg/ft^2 up to 12 months post intervention, while more variability is present in the other study groups. The intervention strategy in the HUD Grantee Evaluation groups frequently included partial or complete window replacement, which was not the case for the other study groups.

As in Table 2, 16 study groups in Table 3 contain information on dust-lead loading measurements immediately after intervention. In the nine study groups of the HUD Grantees evaluation, the three groups of the Baltimore Follow-up Paint Abatement study, and study #2 of the Baltimore Experimental Paint Abatement studies, geometric mean or median dust-lead loadings immediately after intervention were below 100 µg/ft^2 (range: 18-84 µg/ft^2). In particular, study #2 of the Baltimore Experimental Paint Abatement studies saw a substantial decline in the geometric mean from pre-intervention (2,784 µg/ft^2) to immediately post-intervention (19 µg/ft^2). The remaining three study groups (study #1 of the Baltimore Experimental Paint Abatement studies and two study groups from the Baltimore R&M) had geometric mean dust-lead loadings exceeding 180 µg/ft^2 immediately post-intervention, but these groups had geometric mean pre-intervention dust-lead loadings above 300 µg/ft^2.

Except for the Milwaukee grantee, the study groups within the HUD Grantees evaluation had median window sill dust-lead loadings below 100 µg/ft^2 for up to 12 months post-intervention. Only two grantees (Boston and Wisconsin) did not have a decline in median window sill dust-lead loadings over the 12-month period.

In addition to the HUD Grantees evaluation, geometric mean window sill dust-lead loadings remain below 100 µg/ft^2 for up to 12 months post-intervention in the Baltimore Follow-up Paint Abatement study, the Denver CAP study, and the CLEARS (Table 3). However, in studies such as the Baltimore R&M study, the Baltimore Experimental Paint Abatement studies, and the Boston Interim Dust Intervention study, geometric mean dust-lead loadings remain above 100 µg/ft^2 over time. In addition, the 19-month follow-up study group within the Baltimore Follow-up Paint Abatement study and the Baltimore Experimental Paint Abatement studies suggest that geometric mean dust-lead loadings can dip below 100 µg/ft^2 immediately after intervention, but then increase substantially after one year or so.

The summaries in Tables 2 and 3 are calculated across housing units in specified study groups. With the lack of results for individual housing units and the absence of variability estimates associated with these summaries, these summaries do not necessarily indicate what may be occurring in specific units (such as those housing units that see little, if any, change from pre- to post-intervention). Additional information on results within housing units should also be considered if such information is available.

Table 2. Summaries of Pre- and Post-Intervention <u>Floor</u> Dust-Lead Loadings from Studies Evaluating Paint and/or Dust Interventions

Study	Study Group	Pre-Intervention Floor Dust-Lead Loadings[1] (µg/ft²)	Post-Intervention Floor Dust-Lead Loadings[1]: Time Following Intervention	Post-Intervention Floor Dust-Lead Loadings[1]: Summary Value (µg/ft²)
Baltimore Experimental Paint Abatement Studies[2]	Study 1 (6 homes)	1261	Immediately	259
			6 - 9 Months	99
	Study 2 (13 homes)	556	Immediately	20
			1.5 - 3.5 Years	69
Baltimore Follow-up Paint Abatement Study[2]	6-Month Follow-up		Immediately	47
			5 - 7 Months	22
	12-Month Follow-up		Immediately	41
			10 - 14 Months	20
	19-Month Follow-up		Immediately	24
			14 - 24 Months	36
Baltimore R&M Study[3]	All Occupied Units	40.9	Immediately	52.5
			2 Months	40.2
			6 Months	26.5
			12 Months	27.1
			18 Months	24.8
			24 Months	24.1
			48 Months	8.4
	Previously-Abated Units	45.6	2.5 - 4.5 Years	41.1
			3 - 5 Years	39.8
			3.5 - 5.5 Years	37.3
			4 - 6 Years	33.0
	Units Slated for R&M Intervention	58.6	Immediately	52.5
			2 Months	40.2
			6 Months	36.3
			12 Months	39.9
			18 Months	33.3
			24 Months	35.0
	Modern Urban Units	10.0	6 Months	8.1
			12 Months	7.3
			18 Months	7.8
			24 Months	7.1
			48 Months	8.4
Baltimore Traditional/ Modified Paint Abatement Study[2]	Traditional	549	Immediately	4033
			6 Months	714
	Modified	642	Immediately	1626
			6 Months	714
Boston Interim Dust Intervention Study[2]	Automatic Intervention	33.2	6 Months	23.9
	Randomized Intervention	37.3	6 Months	31.4

Table 2. (cont.)

Study	Study Group	Pre-Intervention Floor Dust-Lead Loadings[1] (µg/ft^2)	Post-Intervention Floor Dust-Lead Loadings[1]	
			Time Following Intervention	Summary Value (µg/ft^2)
HUD Grantees[4]	All Grantees	19	Immediately	17
			6 Months	14
			12 Months	14
	Baltimore	41	Immediately	18
			6 Months	42
			12 Months	41
	Boston	24	Immediately	54
			6 Months	16
			12 Months	18
	Massachusetts	24	Immediately	20
			6 Months	11
			12 Months	9
	Milwaukee	14	Immediately	15
			6 Months	10
			12 Months	10
	Minnesota	18	Immediately	18
			6 Months	18
			12 Months	18
	Rhode Island	26	Immediately	7
			6 Months	6
			12 Months	6
	Vermont	28	Immediately	17
			6 Months	21
			12 Months	21
	Wisconsin	9	Immediately	8
			6 Months	6
			12 Months	5
Denver CAP Study[5]	Abated Units		2 Years	21.0
Jersey City CLEARS[6]	Dust Intervention	22	12 Months	15

1 Values are geometric means except for the HUD Grantees studies, where values are medians.
2 Results are adjusted to reflect total dust-lead loadings by exponentiating the "bioavailable" dust-lead loadings as reported in the study to the 1.1416 power.
3 Results for the Baltimore R&M Study are converted from BRM dust-lead loadings to wipe-equivalent loadings.
4 Data collected through September 1997.
5 Results for the Denver CAP study are converted from CAP cyclone dust-lead loadings to wipe-equivalent loadings.
6 An alternative (LWW) wipe sampling method was used in the CLEARS study. No adjustments were made to convert the LWW wipe loadings reported in this study to standard wipe loadings.

Table 3. Summaries of Pre- and Post-Intervention Window Sill Dust-Lead Loadings from Studies Evaluating Paint and/or Dust Interventions

Study	Study Group	Pre-Intervention Sill Dust-Lead Loadings[1] (µg/ft²)	Post-Intervention Sill Dust-Lead Loadings[1]: Time Following Intervention	Post-Intervention Sill Dust-Lead Loadings[1]: Summary Value (µg/ft²)
Baltimore Experimental Paint Abatement Studies[2]	Study 1 (6 homes)	15215	Immediately	737
			6 - 9 Months	958
	Study 2 (13 homes)	2784	Immediately	19
			1.5 - 3.5 Years	199
Baltimore Follow-up Paint Abatement Study[2]	6-Month Follow-up		Immediately	50
			5 - 7 Months	71
	12-Month Follow-up		Immediately	50
			10 - 14 Months	41
	19-Month Follow-up		Immediately	50
			14 - 24 Months	147
Baltimore R&M Study[3]	All Occupied Units	356.2	Immediately	185.4
			2 Months	241.4
			6 Months	138.2
			12 Months	136.2
			18 Months	135.1
			24 Months	117.5
			48 Months	37.1
	Previously-Abated Units	163.5	2.5 - 4.5 Years	107.4
			3 - 5 Years	116.0
			3.5 - 5.5 Years	89.1
			4 - 6 Years	97.6
	Units Slated for R&M Intervention	778.4	Immediately	185.4
			2 Months	241.4
			6 Months	247.0
			12 Months	237.6
			18 Months	246.8
			24 Months	204.9
	Modern Urban Units	45.6	6 Months	41.7
			12 Months	40.0
			18 Months	40.5
			24 Months	34.8
			48 Months	37.1
Baltimore Traditional/ Modified Paint Abatement Study[2]	Traditional	3708	Immediately	11460
			6 Months	4360
	Modified	5209	Immediately	1496
			6 Months	4662

Table 3. (cont.)

Study	Study Group	Pre-Intervention Sill Dust-Lead Loadings[1] (µg/ft²)	Post-Intervention Sill Dust-Lead Loadings[1]	
			Time Following Intervention	Summary Value (µg/ft²)
Boston Interim Dust Intervention Study[2]	Automatic Intervention	787	6 Months	210
	Randomized Intervention	205	6 Months	110
HUD Grantees[4]	All Grantees	258	Immediately	52
			6 Months	97
			12 Months	90
	Baltimore	1191	Immediately	49
			6 Months	87
			12 Months	68
	Boston	174	Immediately	53
			6 Months	48
			12 Months	49
	Massachusetts	328	Immediately	32
			6 Months	77
			12 Months	50
	Milwaukee	264	Immediately	84
			6 Months	231
			12 Months	217
	Minnesota	266	Immediately	66
			6 Months	86
			12 Months	77
	Rhode Island	314	Immediately	18
			6 Months	87
			12 Months	85
	Vermont	147	Immediately	21
			6 Months	60
			12 Months	40
	Wisconsin	150	Immediately	22
			6 Months	37
			12 Months	51
Denver CAP Study[5]	Abated Units		2 Years	66.4
Jersey City CLEARS[6]	Dust Intervention	75	12 Months	24

1 Values are geometric means except for the HUD Grantees studies, where values are medians.
2 Results are adjusted to reflect total dust-lead loadings by exponentiating the "bioavailable" dust-lead loadings as reported in the study to the 1.1416 power.
3 Results for the Baltimore R&M Study are converted from BRM dust-lead loadings to wipe-equivalent loadings.
4 Data collected through September 1997.
5 Results for the Denver CAP study are converted from CAP cyclone dust-lead loadings to wipe-equivalent loadings.
6 An alternative (LWW) wipe sampling method was used in the CLEARS study. no adjustments were made t o convert the LWW wipe loadings reported in this study to standard wipe loadings.

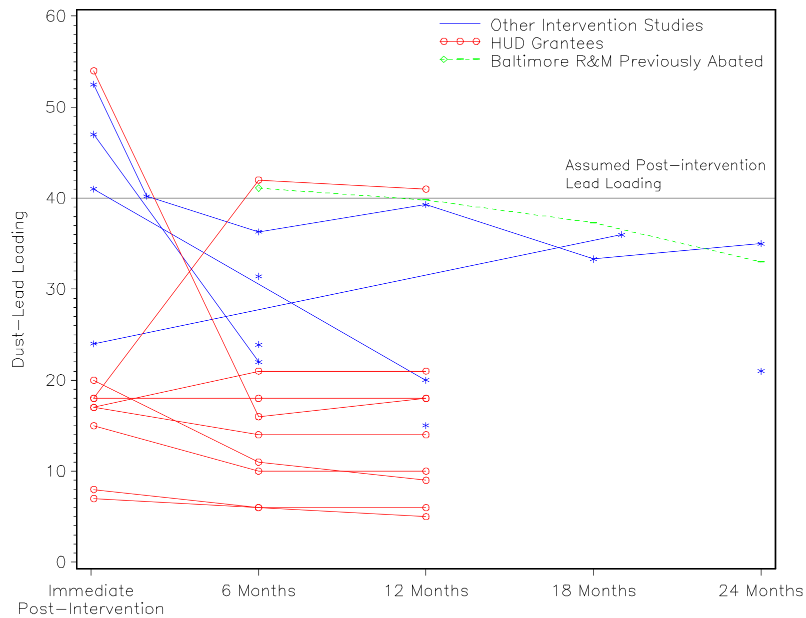

Figure 1. Post-Intervention Floor Dust-Lead Loadings for HUD Grantees Evaluation, Intervention Groups from Other Studies, and Baltimore R&M Previously Abated Group (sampling times relative to enrollment in R&M Study).

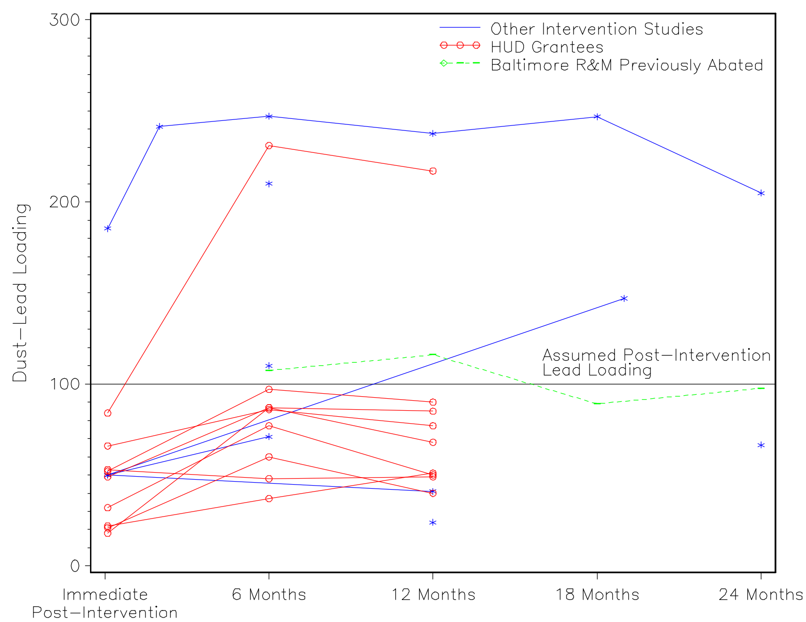

Figure 2. Post-Intervention Window Sill Dust-Lead Loadings for HUD Grantees Evaluation, Intervention Groups from Other Studies, and Baltimore R&M Previously Abated Group (sampling times relative to enrollment in R&M Study) .

REFERENCES

Adgate, JL, Weisel, C, Wang, Y, Rhoads, GG, and Lioy, PJ. (1995) "Lead in House Dust: Relationships between Exposure Metrics." *Environmental Research*. 70:134-147.

Aschengrau, A, Hardy, S, Mackey, P, and Pultinas, D. (1998) "The Impact of Low Technology Lead Hazard Reduction Activities among Children with Mildly Elevated Blood Lead Levels." *Environmental Research*. 79:41-50.

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.

Copley, C. (1995) "East St. Louis Lead Dust Reduction in Homes of At-Risk Children: Pilot Project." Report on Grant NE995974-01 to Region V of the U.S. Environmental Protection Agency. 23 October 1995.

Farfel, MR, Chisolm, JJ, and Rohde, CA. (1994) "The Longer-Term Effectiveness of Residential Lead Paint -Abatement." *Environmental Research*. 66:199-212.

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

Farfel, MR, and Chisolm, JJ. (1990) "Health and Environmental Outcomes of Traditional and Modified Practices for Abatement of Residential Lead-Based Paint." *American Journal of Public Health*. 80(10):1240-1245.

HUD (1991) "The HUD Lead-Based Paint Abatement Demonstration (FHA)." Office of Policy Development and Research, U.S. Department of Housing and Urban Development. August 1991.

Lanphear, BP, Winter, NL, and Weitzman, M. (1996) "A Randomized Trial of the Effect of Dust Control on Children's Blood Lead Levels." *Pediatrics*. 98(1):35.

Lanphear, BP, Winter, NL, Apetz, LJ, Eberly, S, and Weitzman, M. (1995) "A Randomized Trial of the Effect of Dust Control on Children's Blood Lead Levels." Report on Grant NYLPR002-94 Submitted to the U.S. Department of Housing and Urban Development and the National Center for Lead-Safe Housing.

Lioy, PJ, Yiin, L, Adgate, J, Weisel, CP, and Rhoads, GG. (1997) "The Effectiveness of a Home Cleaning Intervention Strategy in Reducing Potential Dust and Lead Exposures." (Submitted to *Journal of Exposure Analysis and Environmental Epidemiology*).

Mackey, P, Aschengrau, A, Balasko, C, Pultinas, D, and Hardy, S. (1996) "Blood Lead Levels Following Environmental Intervention Study," Final Report on Grant H64/CCH108235-03 to the U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, Environmental Hazards & Health Effects, Childhood Lead Poisoning Prevention.

MDE (1995) Final Report on Grant H64/CCH 30 7067-03 by the Maryland Department of the Environment to U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, Environmental Hazards & Health Effects, Childhood Lead Poisoning Prevention. March 1995.

NCLSH and UC (1998) "Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program," Fifth Interim Report. Prepared by the National Center for Lead-Safe Housing and The University of Cincinnati Department of Environment Health for the U.S. Department of Housing and Urban Development. March 1998.

NCLSH and UC (1997) "Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program," Fourth Interim Report. Prepared by the National Center for Lead-Safe Housing and The University of Cincinnati Department of Environment Health for the U.S. Department of Housing and Urban Development. March 1997.

NCLSH (1993) "A Comparison of Five Sampling Methods for Settled Lead Dust: A Pilot Study." Preliminary draft report prepared by the National Center for Lead-Safe Housing. 15 June 1993.

Nedellec, V, Fontaine, A, Luciolli, E, and Bourdillon, F. (1995) "Evaluation of Abatement Interventions in 59 Homes of Lead Poisoned Children," *Rev. Epidem. Et Sante Publ*. 43:485-493.

Rhoads, GG, Ettinger, AS, Goldman, KD, Weisel, CP, Buckley, TJ, and Lioy, PJ. (1996) "The Effect of a Dust Lead Control Program Combined with Health Education on Blood Lead in Toddler: A Randomized Study," (Abstract) Submitted for Presentation at the Annual Conference of the *American Public Health Association*, November 1996.

USEPA (1998) "Review of Studies Addressing Lead Abatement Effectiveness: Updated Edition." Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 747-B-98-001, December 1998.

USEPA (1997a) "Conversion Equations for Use in Section 403 Rulemaking." Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 747-R-96-012, December 1997.

USEPA (1997b) “Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on the First Year of Follow-up.” Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 747-R-97-001, August 1997.

USEPA (1997c) “Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on the Two Years of Follow-up.” Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 747-R-97-005, December 1997.

USEPA (1996a) “Comprehensive Abatement Performance Study. Volume I: Summary Report.” Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 230-R-94-013a, April 1996.

USEPA (1996b) “Comprehensive Abatement Performance Study. Volume II: Detailed Statistical Results.” Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 230-R-94-013b, April 1996.

USEPA (1996c) “Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Pre-Intervention Findings.” Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 747-R-95-012, August 1996.

USEPA (1995a) “Review of Studies Addressing Lead Abatement Effectiveness.” Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. EPA 747-R-95-006, July 1995.

USEPA (1987) “Baltimore Integrated Environmental Management Project - Phase II Report: Reducing the Hazards from Abatement of Lead Paint.” Final Report to the U.S. Environmental Protection Agency.

Vostal, JJ, Taves, E, Sayre, JW, and Charney, E. (1974) “Lead Analysis of House Dust: A Method for the Detection of Another Source of Lead Exposure in Inner City Children.” *Environmental Health Perspectives*. May 1974, 91-97.

APPENDIX A

INFORMATION ON THE INTERVENTION STUDIES INCLUDED IN TABLE 1

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Baltimore (MD) Dust Control Study

- Conducted in 1981 to assess whether lead-based paint abatement followed by periodic dust control would be more effective in reducing blood-lead concentration than performing only lead-based paint abatement.

- The study targeted housing units containing lead-based paint and children aged 15-72 months of age with at least two confirmed blood-lead concentration measurements between 30-49 µg/dL.

- Two groups of housing units (a control group of 35 homes and an experimental group of 14 homes) 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. No extensive clean-up procedures were required following the abatements.

- The experimental group received periodic dust-control (twice-monthly visits by a dust-control team) involving wet-mopping all rooms in the residence where dust-lead loadings in an initial survey exceeded 100 µg/ft^2.

- In the experimental group, dust samples 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. The samples were collected at recruitment and both before and after each dust-control measure was performed.

Baltimore (MD) Experimental Paint Abatement Studies

- Studies to demonstrate and evaluate experimental lead-based paint abatement practices developed in response to the inadequacies uncovered in the Baltimore (MD) Traditional/Modified Paint Abatement Study.

- The experimental practices called for 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.

- One study involving 6 housing units (poorly-maintained, had multiple lead-based paint hazards, built in the 1920s) received abatements from 10/86-1/87 as part of a pilot study examining the experimental procedures. Four units were vacant, and two contained lead-poisoned children. This study evaluated short-term abatement efficacy (up to 9 months).

- Dust samples from the 6 housing units were collected immediately before abatement, during abatement, after the final clean-up, and at 1, 3, and 6-9 months following abatement.

- Another study which evaluated longer-term abatement efficacy (1.5-3.5 years) involved 13 occupied housing units which received experimental abatements from 1988-1991 by local pilot projects.

- Dust samples from the 13 housing units were collected from 12/91 - 01/92 at the same locations, where possible, that had been sampled pre- and immediately post-abatement.

- Alcohol-treated wet wipes were used to collect dust samples.

Baltimore (MD) Follow-up Paint Abatement Study

- Paint interventions (encapsulation, off-site and on-site stripping, and replacement) were performed (from floor to ceiling) on all interior and exterior surfaces where lead content of paint exceeded 0.7 mg/cm^2 by XRF or 0.5% by weight by wet chemical analysis. Abatements took place in unoccupied dwellings or after occupants were relocated.

- Lead-contaminated dust was contained and minimized during the abatement.

- Extensive clean-up activities (including HEPA vacuuming and off-site waste disposal) followed the abatement to ensure clearance. Clearance levels for floors, window sills, and window wells were set at 200 µg/ft^2, 500 µg/ft^2, and 800 µg/ft^2, respectively.

- Wipe dust-lead loading samples were taken upon clearance and at approximately 6, 12, and 19 months post-intervention from floors, window sills, and window wells in rooms where the child spent time.

- By 19 months post-intervention, only 5% of the homes were above clearance for floors, while 42% and 47% of the homes were above clearance levels for window sills and window wells, respectively.

Baltimore (MD) Repair & Maintenance (R&M) Study

- Study begun in 1993 to measure the short-term (2 to 6 months) and long-term (12 to 24 months) changes in dust-lead loadings and concentrations and in children's blood-lead concentrations associated with conducting R&M interventions, and to make comparisons with houses that had undergone previous comprehensive abatement, as well as a group of modern urban houses.

- Three types of dwellings were recruited in this study: 16 dwellings that were previously abated (in 1988-1992), 75 dwellings slated to receive R&M interventions, and 16 modern urban dwellings (assumed to be free of lead-based paint).

- The 75 R&M dwellings were older (mostly pre-1940), low-income dwellings which were divided into three equal groups according to the intervention performed in this study; the R&M-I group had low-level interventions (wet scraping, limited repainting, wet cleaning with TSP, HEPA vacuuming, placing an entryway mat, exterior surface stabilization, cleaning supplies and education to residents), the R&M-II group had intermediate-level interventions (R&M-I interventions plus treatments to floors, windows, and doors to reduce abrasion), and the R&M-III group had high-level interventions (R&M-II interventions plus trim replacement and encapsulation). The remaining dwellings acted as control dwellings.

- The BRM vacuum method was used to collect dust samples in this study (a modified HVS_3 cyclone collector). Floor and window sill dust samples were composites across multiple rooms. The environmental sampling design was as follows:

Campaign	Type of Data [1]							
	Blood		Dust		Soil		Water	
	RM [2]	Control [3]	RM	Control	RM	Control	RM	Control
Initial	√[a]	√	√	√	√	√	√[a]	√
Immediate Post-R&M	√		√		√		√[b]	
2 Months Post-R&M	√		√					
6 Months Post-R&M	√	√	√	√	√	√	√	√
12 Months Post-R&M	√	√	√	√				
18 Months Post-R&M	√	√	√	√	√	√	√	√
24 Months Post-R&M	√	√	√	√				

1. A '√' indicates that the data were collected for all R&M groups or all control groups. Symbol '√[a]' indicates that data collected only for R&M I and II groups, and '√[b] ' only for R&M II and III.
2. RM denotes the component including three R&M groups: R&M I, R&M II, and R&M III.
3. Control denotes the component including two control groups: Previously Abated and Modern Urban.

Baltimore (MD) Traditional/Modified Paint Abatement Study

- Conducted from 1984-1985 to evaluate the health and environmental impact of "traditional" and "modified" Baltimore practices for abating lead-based paint.

- The study contained housing units with multiple interior surfaces coated with lead-based paint and containing at least one child with a blood-lead concentration exceeding 30 µg/dL.

- "Traditional" abatements (conducted in 53 housing units) addressed 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/cm² by XRF or 0.5% by weight by wet chemical analysis was denoted hazardous. Open-flame burning and sanding techniques were commonly used, the abated surfaces were not repainted, and clean-up typically entailed, at most, dry sweeping.

- "Modified" abatements (conducted in 18 housing units) included the use of heat guns for paint removal and the repainting of abated surfaces. Furnishings were protected during abatement. In addition, clean-up efforts were conducted that involved wet-mopping with a high phosphate detergent, vacuuming with a standard shop vacuum, and off-site disposal of debris. In addition, worker training, protection, and supervision were provided.

- Neither traditional nor modified abatements considered window wells.

- Dust samples were obtained using a alcohol-treated wipe within a defined area template (1 ft²).

- Increased dust-lead loadings were measured immediately following traditional abatements (usually within two days) on or in close proximity to abated surfaces. 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.

- 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. In addition, the activities further elevated blood-lead concentrations.

Boston (MA) Interim Dust Intervention Study

- Children under 4 years of age with modestly-elevated blood-lead concentration (11-24 µg/dL) and living in homes containing lead-based paint on at least two window sills or wells were targeted for participation. Lead hazard reduction activities were not previously conducted in these homes.

- Units with severe household lead hazards (i.e., paint chips on floors, large amounts of loose dust or paint chips in window wells, or holes larger than one inch wide in walls containing lead-based paint) were placed into an "automatic intervention" group (n=22).

- Remaining units were randomly assigned to a "randomized intervention" group (n=22) or a "randomized comparison" group (n=19).

- Units in the two intervention groups received a one-time paint and/or dust intervention. The intervention was considered "low-technology" and consisted of HEPA vacuuming all window well, window sill, and floor surfaces; washing window well and window sill surfaces with a tri-sodium phosphate (TSP) and water solution; repairing holes in walls; and re-painting window well and window sill surfaces to seal chipping or peeling paint. These units also received outreach and educational information including a demonstration of effective housekeeping techniques and monthly reminders with instructions to wash hard surface floors, window sills and wells with a TSP and water solution at least twice a week.

- The "randomized comparison" group received only the outreach visit, in which the home was visually assessed for lead hazards and the family was educated about the causes and prevention of lead poisoning. They were also provided with cleaning instructions and a free sample of TSP cleaning solution.

- 16 study units had permanent lead-based paint hazard remediation performed outside of the study protocol during the 6-month follow-up period. It is uncertain whether data for these units were treated differently in the study as a result.

- Dust samples were collected from floors, window sills, and window wells at baseline and 6 months post-intervention in all units, and at one month post-intervention for the two intervention groups. However, results were not reported for the one-month post-intervention campaign.

- Dust, soil, and water samples were analyzed using atomic absorption spectrophotometry (AAS). The detection limit for dust-lead loading results was 30 µg/ft^2.

- At 6 months post-intervention, geometric mean floor dust-lead loadings had decreased slightly for both intervention groups and increased in the comparison group. Geometric mean window sill dust-lead loadings decreased in all three groups, and geometric mean window well dust-lead loadings decreased for both intervention groups, but remained the same for the comparison group. None of the changes in dust-lead loadings was statistically significant.

East St. Louis (IL) Educational Intervention Study

- Children were identified for the study through a screening program for children receiving public assistance.

- During an initial visit to each home, an XRF paint survey was conducted, and areas with high lead loadings were pointed out to the residents. Lead educators, hired from within the community, provided instruction on cleaning and hygiene. Written materials and a videotape on reducing lead exposure were also provided.

- At the initial visit and at three months following this visit (for homes where the residents reported that they had cleaned at least once using the recommended procedures), at least three dust-wipe samples were collected from smooth surfaces in the home. In addition, two vacuum (HVS-3) samples were collected from carpets in the entry and bedroom, or other play area.

- Participating families were contacted regularly throughout the course of the study to reinforce the importance of regular, thorough cleaning.

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

- A formal evaluation of this ongoing study is being conducted to determine the effectiveness of various abatement methods used by State and local governments (who are HUD grantees) to reduce lead-based paint hazards in housing.

- Data collection began in 1994 and is expected to continue through 1999.

- Enrollment criteria varied among the different grantees and included targeting high-risk neighborhoods, homes with a lead-poisoned child, and unsolicited applications.

- Grantees were given the flexibility to select the type and intensity of the lead treatments for any particular unit. The intensity of an intervention is reported by location (interior, exterior, or site) and consists of a number representing the type of intervention performed in that location. The interventions range from taking no action, to a simple cleaning, to window replacement or full lead-based paint abatement. Some interim controls on soil (e.g., cover), as well as soil removal, were also performed.

- The grantees followed the same sampling protocols when collecting environmental samples (including dust using wipe techniques) and used standard forms developed specifically for the evaluation.

- Dust samples are collected from occupied housing units at four times during the study: at pre-intervention, immediately after intervention, and at 6 and 12 months following intervention. Nine of the 14 grantees participating in this evaluation are also collecting data at 24 and 36 months following intervention (these data have not yet been collected).

<u>HUD Abatement Demonstration Program/</u>
<u>EPA Comprehensive Abatement Performance (Denver CAP) Study</u>

- The FHA portion of the HUD Abatement Demonstration Program ("HUD Demo") was conducted to estimated the comparative costs of alternative methods of lead-based paint abatement, to assess the efficacy of these methods, and to confirm the adequacy of worker protection safeguards during abatement.

- In the HUD Demo, lead-based paint abatements were performed in 172 HUD-owned, single-family properties located in seven cities across the country.

- Wipe dust samples were collected immediately following intervention and cleaning in the HUD Demo to evaluate whether lead levels were below 200 $\mu g/ft^2$ for floors and 500 $\mu g/ft^2$ for window sills. Repeated iterations of cleaning and dust sampling were performed if additional cleaning was deemed necessary.

- The Denver CAP study was a follow-up to the HUD Demo performed in Denver, CO. The objectives of the Denver CAP study were to assess the long-term efficacy of two primary abatement methods (encapsulation/enclosure and removal methods), to characterize lead levels in dust and soil in unabated homes and homes abated by different methods, to investigate the relationship between household dust-lead and lead from other sources (i.e., soil and air ducts), and to compare dust-lead loading results from cyclone vacuum sampling and wipe sampling protocols.

- The Denver CAP study collected approximately 30 dust and soil samples at each of 52 occupied houses in Denver. Of these houses, 39 had lead-based paint abatements performed approximately two years earlier as part of the HUD Demo. The remaining 17 houses were considered within the HUD Demo, but were found to be free of lead-based paint and therefore had no abatements performed.

- The Denver CAP study used a cyclone vacuum for collecting dust samples, where this vacuum was designed especially for this study. Dust samples were collected from the floor perimeter, window sills, window wells, entryway floors, and air ducts in either two or three rooms. Some wipe dust samples were also collected to make comparisons between wipe and vacuum dust-lead loadings.

- For window sills within 10 houses, pre-abatement dust-lead loadings and loadings measured during the Denver CAP study both averaged between 175-200 µg/ft^2 (i.e., there was no evidence of significant differences between pre- and post-intervention dust-lead loadings). However, no adjustment was made between the wipe and vacuum methods used in pre- and post-intervention, respectively. A similar comparison between pre- and post-intervention dust-lead loadings for floors was not possible due to a lack of sufficient pre-intervention data.

- Abatements were found to be effective in that no significant difference in dust-lead loadings were observed between abated and unabated units in the Denver CAP study (with the exception of dust from air ducts).

<u>Jersey City (NJ) Children's Lead Exposure and Reduction (CLEAR) Dust Intervention Study</u>

- Children under 3 years of age and at risk for elevated blood-lead concentration were targeted for participation.

- Lead hazard intervention consisted of biweekly assistance with home dust control (which included wet mopping of floors, damp-sponging of walls and horizontal surfaces, and HEPA vacuuming) and a series of educational sessions about lead. The cleaning teams provided the education during the course of their visits and mainly focused on teaching the caretakers how to clean the home.

- Dust-wipe samples were collected from uncarpeted floors in the kitchen and the floor of one other room frequented by the enrolled child.

- This analysis indicated that a thorough cleaning program reduced the geometric mean of the dust and lead loading and found that 68%, 75%, and 81% of the Lead Group (Study) homes had a reduction in lead loading on the kitchen floors, bedroom floors, and window sills, respectively.

<u>Paris Paint Abatement Study</u>

- Children less than 6 years of age, identified as severely lead-poisoned, and living in homes with lead-based paint were targeted for participation.

- A one-time paint intervention was performed, consisting of chemical stripping with caustic products, encapsulation (consisting of covering the toxic paint with coating material which prevents the dispersion of chips and particles into the home), replacement of antiquated elements and paint coatings of lead-based paints, and a final dust cleaning. Chemical stripping, using Peel Away™, was used on 52% of the items abated, a combination of stripping and encapsulation was used on 36% of the items abated, and a combination of encapsulation and replacement was used on 12% of the abated items. Families were relocated during abatement.

- Dust samples were collected in 29 homes at baseline, during the intervention, and at 1 to 2 months, 3 to 6 months, and 7 to 12 months post-intervention. Dust sampling was done by wiping the floor 1 meter from the wall, over an area of 30x30 cm^2, with a paper towel impregnated with alcohol.

- For 11 homes having an initial dust-lead loading greater than 92.9 $\mu g/ft^2$, median decreases were 144 $\mu g/ft^2$ at 1 to 2 months follow up and 157 $\mu g/ft^2$ at 3 to 6 months post-intervention.

- By 6 to 28 months post-intervention, the maximum dust-lead loadings were less than 92.9 $\mu g/ft^2$ for 40 out of 45 households.

<u>Rochester (NY) Educational Intervention Study</u>

- Included 104 of the 205 children in the Rochester Lead-in-Dust study, aged 12-31 months at enrollment, with low to moderate blood-lead concentration. Households were randomly assigned to an intervention or control group.

- Aim of the study was to determine the effectiveness of simple dust control by household members as a means of reducing children's blood-lead concentration.

- A trained interviewer visited families assigned to the intervention group. The interviewer stressed the importance of dust control as a means of reducing lead exposure and provided the household with cleaning supplies (paper towels, spray bottles and Ledisolv, a detergent developed specifically for lead contaminated house dust). Families were instructed to clean the entire house once every three months, interior window sills, window wells and floors near windows once every month, and carpets once a week with a vacuum cleaner, if available.

- For families assigned to the control group, only a brochure was provided containing information about lead poisoning and its prevention.

- Dust samples (using a K-mart brand of baby wipes) were collected at the time of the home visit (baseline) and at seven months following the visit. Locations of dust samples included entryway floors and the kitchen, as well as from the floors, interior window sills and window wells of the child's principal play area.

APPENDIX B:

DETAILED SUMMARY TABLES

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Table B-1. Summary of Floor Dust-Lead Loadings, Under Wipe Dust Sampling Techniques, at Pre- and Post-Intervention

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Floor Dust-Lead Loadings			Post-Intervention Floor Dust-Lead Loadings				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)
Baltimore Experimental Paint Abatement Studies[2]	Study 1 (6 homes)	70	GM (95% CI)	1261 (908, 1761)	Immediately	70	GM (95% CI)	259 (196, 366)				
					6-9 Months	63	GM (95% CI)	99 (79, 136)				
	Study 2 (13 homes)	42	GM (95% CI)	556 (289, 1074)	Immediately	47	GM (95% CI)	20 (9.8, 40)				
					1.5 - 3.5 Years	71	GM (95% CI)	69 (40, 125)				
Baltimore Follow-up Paint Abatement Study[2]	6-Month Follow-up				Immediately Following Clearance	29	GM (95% CI)	29 (20,41)				
					5-7 Months		GM (95% CI)	22 (15, 31)				
	12-Month Follow-up				Immediately Following Clearance	27	GM (95% CI)	41 (25, 63)				
					10-14 Months		GM (95% CI)	20 (15, 29)				
	19-Month Follow-up				Immediately Following Clearance	22	GM (95% CI)	24 (14, 38)				
					14-24 Months		GM (95% CI)	36 (20, 63)				

Table B-1. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Floor Dust-Lead Loadings			Post-Intervention Floor Dust-Lead Loadings				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)
Baltimore R&M Study[3]	All Occupied Units	90	GM	40.9	Immediately	37	GM	52.5				
					2 Months	37	GM	40.2				
					6 Months	66	GM	26.5				
					12 Months	66	GM	27.1				
					18 Months	64	GM	24.8				
					24 Months	62	GM	24.1				
					48 Months	7	GM	8.4				
	Previously-Abated Units	16	GM	45.6	2.5 - 4.5 Years	14	GM	41.1				
					3 - 5 Years	14	GM	39.8				
					3.5 - 5.5 Years	13	GM	37.3				
					4 - 6 Years	13	GM	33.0				
	Units Slated for R&M Intervention	58	GM	58.6	Immediately	37	GM	52.5				
					2 Months	37	GM	40.2				
					6 Months	37	GM	36.3				
					12 Months	37	GM	39.9				
					18 Months	37	GM	33.3				
					24 Months	35	GM	35.0				

Table B-1. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Floor Dust-Lead Loadings			Post-Intervention Floor Dust-Lead Loadings				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)
Baltimore R&M Study[3]	Modern Urban Units	16	GM	10.0	6 Months	15	GM	8.1				
					12 Months	15	GM	7.3				
					18 Months	14	GM	7.8				
					24 Months	14	GM	7.1				
					48 Months	7	GM	8.4				
Baltimore Traditional/ Modified Paint Abatement Study[2]	Traditional	280	GM (95% CI)	549 (482, 645)	Immediately	271	GM (95% CI)	4033 (3269, 4936)				
					6 Months	234	GM (95% CI)	714 (594, 834)				
	Modified	82	GM (95% CI)	642 (433, 908)	Immediately	50	GM (95% CI)	1626 (1082, 2418)				
					6 Months	57	GM (95% CI)	714 (526, 983)				
Boston Interim Dust Intervention Study[2]	Automatic Intervention	10	GM	33	6 Months	10	GM	24				
	Randomized Intervention	9	GM	37	6 Months	9	GM	31				
East St. Louis Educational Intervention Study[2]	Intervention Group	30	AM	1095	3 Months	30	AM	486	3 Months	30	Percent Change	-56%
			GM	1080			GM	103				-87%

Table B-1. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Floor Dust-Lead Loadings			Post-Intervention Floor Dust-Lead Loadings				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)
HUD Grantees	All Grantees	557	Median	19	Immediately Post	557	Median	17	Immediately Post	557	Percent Change	-11%
					6 Months		Median	14	6 Months			-26%
					12 Months		Median	14	12 Months			-26%
	Baltimore	32	Median	41	Immediately Post	32	Median	18				
					6 Months		Median	42				
					12 Months		Median	41				
	Boston	28	Median	24	Immediately Post	28	Median	54				
					6 Months		Median	16				
					12 Months		Median	18				
	Mass.	42	Median	24	Immediately Post	42	Median	20				
					6 Months		Median	11				
					12 Months		Median	9				
	Milwaukee	170	Median	14	Immediately Post	170	Median	15				
					6 Months		Median	10				
					12 Months		Median	10				

Table B-1. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Floor Dust-Lead Loadings			Post-Intervention Floor Dust-Lead Loadings				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)
HUD Grantees	Minnesota	105	Median	18	Immediately Post	105	Median	18				
					6 Months		Median	18				
					12 Months		Median	18				
	Rhode Island	31	Median	26	Immediately Post	31	Median	7				
					6 Months		Median	6				
					12 Months		Median	6				
	Vermont	43	Median	28	Immediately Post	43	Median	17				
					6 Months		Median	21				
					12 Months		Median	21				
	Wisconsin	48	Median	9	Immediately Post	48	Median	8				
					6 Months		Median	6				
					12 Months		Median	5				
CAP study[4]	Unabated homes				2 years	51	GM (25th %ile) (75th %ile)	15 (4.1) (47)				
	Abated homes				2 years	187	GM 25th %ile 75th %ile	21 (4.9) (76)				

Table B-1. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Floor Dust-Lead Loadings			Post-Intervention Floor Dust-Lead Loadings				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft^2)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft^2)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft^2)
Jersey City (NJ) CLEARS	Dust Intervention	42	GM	22	12 Months	40	GM	15				
Paris Paint Abatement Study	Intervention Group	24	Median	83.6					During Intervention	24	Median	+697
									1-2 Months	24	Median	-33.9
									3-6 Months	24	Median	-45.5
Rochester Educational Intervention Study	Intervention Group - Uncarpeted Floors								7 Months	80	Median Absolute Change (IQ Range)	-9.9 (-20,-2.3)
	Intervention Group - Carpeted Floors								7 Months	80		-6.9 (-10,-2.5)

1 GM = geometric mean. AM = arithmetic mean. CI = Confidence Interval.
2 Results (for geometric means and medians ONLY) are adjusted to reflect total dust-lead loadings by exponentiating the "bioavailable" dust-lead loadings as reported in the study to the 1.1416 power.
3 Results for the Baltimore R&M Study are converted from BRM dust-lead loadings to wipe-equivalent loadings.
4 Results for the CAP study are converted from CAPS cyclone dust-lead loadings to wipe-equivalent loadings.

Table B-2. Summary of Window Sill Dust-Lead Loadings, Under Wipe Dust Sampling Techniques, at Pre- and Post-Intervention

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Sill Dust-Lead Results			Post-Intervention Sill Dust-Lead Results				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)
Baltimore Experimental Paint Abatement Studies[2]	Study 1 (6 homes)	34	GM (95% CI)	15215 (9389, 24618)	Immediately Post	35	GM (95% CI)	737 (411, 1364)				
					6-9 Months	31	GM (95% CI)	958 (526, 1681)				
	Study 2 (13 homes)	53	GM (95% CI)	2784 (1322, 5891)	Immediately Post	54	GM (95% CI)	19 (9.8, 35)				
					1.5 - 3.5 Years	59	GM (95% CI)	199 (119, 331)				
Baltimore Follow-up Paint Abatement Study[2]	6-Month Follow-up				Immediately Following Clearance	27	GM (95% CI)	50 (32, 81)				
					5-7 Months	27	GM (95% CI)	71 (43, 119)				
	12-Month Follow-up				Immediately Following Clearance	26	GM (95% CI)	50 (31, 81)				
					10-14 Months	26	GM (95% CI)	41 (49, 132)				
	19-Month Follow-up				Immediately Following Clearance	19	GM (95% CI)	50 (19, 52)				
					14-24 Months	19	GM (95% CI)	147 (66, 324)				

Table B-2. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Sill Dust-Lead Results			Post-Intervention Sill Dust-Lead Results				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft²)
Baltimore R&M Study[3]	All Occupied Units	90	GM	356.2	Immediately	37	GM	185.4				
					2 Months	37	GM	241.4				
					6 Months	66	GM	138.2				
					12 Months	66	GM	136.2				
					18 Months	64	GM	135.1				
					24 Months	62	GM	117.5				
					48 Months	7	GM	37.1				
	Previously-Abated Units	16	GM	163.5	2.5 - 4.5 Years	14	GM	107.4				
					3 - 5 Years	14	GM	116.0				
					3.5 - 5.5 Years	13	GM	89.1				
					4 - 6 Years	13	GM	97.6				
	Units Slated for R&M Intervention	58	GM	778.4	Immediately	37	GM	185.4				
					2 Months	37	GM	241.4				
					6 Months	37	GM	247.0				
					12 Months	37	GM	237.6				
					18 Months	37	GM	246.8				
					24 Months	35	GM	204.9				

Table B-2. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Sill Dust-Lead Results			Post-Intervention Sill Dust-Lead Results				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic ($\mu g/ft^2$)
Baltimore R&M Study[3]	Modern Urban Units	16	GM	45.6	6 Months	15	GM	41.7				
					12 Months	15	GM	40.0				
					18 Months	14	GM	40.5				
					24 Months	14	GM	34.8				
					48 Months	7	GM	37.1				
Baltimore Traditional/ Modified Paint Abatement Study[2]	Traditional	249	GM (95% CI)	3708 (2953, 4600)	Immediately Post	246	GM (95% CI)	11460 (8929, 14654)				
					6 Months	199	GM (95% CI)	4360 (3356, 5674)				
	Modified	45	GM (95% CI)	5209 (3765, 7246)	Immediately Post	64	GM (95% CI)	1496 (1058, 2114)				
					6 Months	66	GM (95% CI)	4662 (3126, 6961)				
Boston Interim Dust Intervention Study[2]	Automatic Intervention	10	GM	787	6 Months	10	GM	210				
	Randomized Intervention	9	GM	205	6 Months	9	GM	110				

Table B-2. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Sill Dust-Lead Results: N	Pre-Intervention: Type of Statistic[1]	Pre-Intervention: Value of Statistic (µg/ft²)	Post-Intervention Sill Dust-Lead Results: Time Following Intervention	Post-Intervention: N	Post-Intervention: Type of Statistic[1]	Post-Intervention: Value of Statistic (µg/ft²)	Difference from Pre-Intervention: Time Following Intervention	Difference: N	Difference: Type of Statistic[1]	Difference: Value of Statistic (µg/ft²)
HUD Grantees	All Grantees	547	Median	258	Immediately Post	547	Median	52	Immediately Post	547	Median Percent Change	-80%
					6 Months		Median	97	6 Months			-62%
					12 Months		Median	90	12 Months			-65%
	Baltimore	32	Median	1191	Immediately Post	32	Median	49				
					6 Months		Median	87				
					12 Months		Median	68				
	Boston	29	Median	174	Immediately Post	29	Median	53				
					6 Months		Median	48				
					12 Months		Median	49				
	Mass.	43	Median	328	Immediately Post	43	Median	32				
					6 Months		Median	77				
					12 Months		Median	50				
	Milwaukee	166	Median	264	Immediately Post	166	Median	84				
					6 Months		Median	231				
					12 Months		Median	217				

Table B-2. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Sill Dust-Lead Results			Post-Intervention Sill Dust-Lead Results				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft^2)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft^2)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft^2)
HUD Grantees	Minnesota	108	Median	266	Immediately Post	108	Median	66				
					6 Months		Median	86				
					12 Months		Median	77				
	Rhode Island	31	Median	314	Immediately Post	31	Median	18				
					6 Months		Median	87				
					12 Months		Median	85				
	Vermont	32	Median	147	Immediately Post	32	Median	21				
					6 Months		Median	60				
					12 Months		Median	40				
	Wisconsin	45	Median	150	Immediately Post	45	Median	22				
					6 Months		Median	37				
					12 Months		Median	51				
CAP study[4]	Unabated homes				2 years	38	GM (25th %ile) (75th %ile)	34 (7.1) (163)				
	Abated homes				2 years	78	GM 25th %ile 75th %ile	66 (11) (339)				

Table B-2. Continued

Name of Study	Group of Housing Units Within the Study	Pre-Intervention Sill Dust-Lead Results			Post-Intervention Sill Dust-Lead Results				Difference from Pre-Intervention			
		N	Type of Statistic[1]	Value of Statistic (µg/ft^2)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft^2)	Time Following Intervention	N	Type of Statistic[1]	Value of Statistic (µg/ft^2)
Jersey City (NJ) CLEARS	Dust Intervention	39	GM	75	12 Months	36	GM	24				
Rochester Educational Intervention Study	Intervention Group								7 Months	80	Median Absolute Change (IQ Range)	-58 (-154,-10)

1 GM = geometric mean. AM = arithmetic mean. CI = Confidence Interval.
2 Results (for geometric means and medians ONLY) are adjusted to reflect total dust-lead loadings by exponentiating the "bioavailable" dust-lead loadings as reported in the study to the 1.1416 power.
3 Results for the Baltimore R&M Study are converted from BRM dust-lead loadings to wipe-equivalent loadings.
4 Results for the CAP study are converted from CAPS cyclone dust-lead loadings to wipe-equivalent loadings.

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13. ABSTRACT (Maximum 200 words)

This report is a comprehensive review of the scientific literature regarding the effectiveness of lead hazard intervention. This report updates the July 1995 report (EPA 747-R-95-006) of the same title and reproduces much of the material in that report. There is a growing body of evidence that lead hazard interventions can reduce children's blood-lead concentrations and dust-lead levels in homes. However, no single intervention strategy stands out as markedly superior. Comparable reductions in blood-lead concentration were observed following lead hazard abatement, interim control, and educational intervention strategies. In addition, seemingly similar approaches have been effective in some populations, but not in others. Thus, it appears that other relevant factors should determine the strategy applied in a given situation.

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