The National Center for Lead-Safe Housing

Does Residential Lead-Based Paint Hazard Control Work?

A Review of the Scientific Evidence

By: Catherine Staes, BSN, MPH
Richard Rinehart, SM, CIH

April 4, 1995

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Catherine Staes, BSN, MPH and Richard Rinehart, SM, CIH

For:

The National Center for Lead-Safe Housing
10227 Wincopin Circle, Suite 205
Columbia, Maryland 21044

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Preface

The National Center for Lead-Safe Housing commissioned this independent review of the available scientific evidence on the efficacy of controlling lead-based paint hazards in housing to fill an important gap. Strong evidence linking lead-based paint hazards and childhood lead poisoning has accumulated for almost a century and has been well summarized elsewhere. Yet the studies of various types of lead hazard control methods and how well they protect the health of children, the public, and workers have not been compiled until now. This report will prove useful to local, federal and state agencies, legislatures, insurance companies, financial institutions, researchers, parents and most of all to the children at risk.

When taken as a group, the studies show that carefully-executed hazard control methods are effective in reducing children's blood lead levels and/or the dust lead levels in their houses. The data are shown in Tables A and B in the Executive Summary. The evidence shows that blood lead levels appear to decline anywhere from 6% to 23% over a period of 6 months to a year following hazard control. Another study shows that an 84%-96% decline in dust lead levels can be maintained for at least 3½ years following abatement (leaded dust is a major route of exposure).

Of course, the population served by these control measures is much larger than the current occupants. Many future generations of at-risk children will also benefit from living in lead-safe houses. In other words, primary prevention of childhood lead poisoning makes good sense for both future generations and children at risk right now.

This review appears at an especially important turning point in our nation's continuing effort to eliminate the epidemic of childhood lead poisoning. Efforts to limit lead in food and gasoline that were launched over the past few decades have been enormously effective in achieving major reductions in blood lead levels across the nation, a decline recently documented in the latest National Health and Nutrition Evaluation Survey. At the same time, the authors of the survey state that we have already seen most of the benefit from these earlier efforts and that continued progress in reducing blood lead levels will stop if we do not address the remaining sources. The inescapable fact is that deteriorating lead-based paint (and the contaminated dust and soil it produces) is responsible for most poisoning today. Right now, 1.7 million children still have unacceptably high levels of lead in their blood, and millions more will join them in years to come if we fail to act on what we know.

During the past several years, an unnecessarily divisive debate has raged over whether interim controls or abatement have been shown to be effective. Some view interim controls to be the only practical response, given the financial condition of much of the nation's low-income housing stock and the lack of funds to complete even basic control measures. Others view abatement to be the only effective response, since interim controls demand a heightened commitment to housing management that is patently unrealistic in the dwellings posing the greatest risks, where housing is operated by owners and managers who are either unwilling or incapable of carrying out essential management practices.

This report demonstrates that *both* strategies are effective. In fact, both strategies have been integrated successfully in the nation's only truly on-going, long term primary prevention effort, the public housing program. Here, immediate hazards are identified and controlled as well as insured relatively quickly and inexpensively, while long-term but deliberate progress is slowly being made to render all such dwellings permanently lead-safe. In short, interim controls and abatement are complementary, not contradictory, activities.

The following pages show that the degree of effectiveness varies with the baseline blood lead level. It appears that the extent of the blood lead decline is most pronounced when the child's baseline blood lead level is already elevated. At lower blood lead levels, the effects are more modest, as expected. This review also documents the adverse effects that result when the work is conducted without proper controls, causing dust lead and blood lead levels to increase, despite good intentions. In short, enough is now known to take action with a reasonable degree of certainty that the harmful effects of haphazard abatement and careless home renovation or remodeling projects that disturb lead-based paint can be avoided. We can now say with confidence that modern hazard control techniques will be beneficial, not harmful, as long as the necessary quality control, training, licensing and certification systems are developed and enforced. The studies reviewed here make it clear that the most important and necessary quality control step is to ensure that clearance examinations are conducted to determine whether or not containment and cleanup were adequate and to ensure that the house is safe to occupy.

Of course, a number of issues should be investigated and clarified further. Chief among them is the relative longevity and cost-effectiveness of both interim control and abatement technologies. Quantifying the benefits in *preventing* the "usual" rise in blood lead levels at 1-2 years of age by primary prevention is also needed. Without such knowledge, widespread practical implementation of lead hazard controls in housing will remain elusive, particularly in dwellings where rents are low, financial resources are limited, and housing management is deficient.

The National Center for Lead-Safe Housing and other organizations are in the midst of research that, in the years to come, will provide further insight into the best methods of controlling lead-based paint hazards in housing. We hope that this report will provide the foundation to continue the successes of earlier years in preventing childhood lead poisoning.

The fact that previous successes have been achieved demonstrates that controlling exposures to lead provides direct health benefits, *not* that efforts to control childhood lead poisoning are no longer needed. There are some who assert that we should stop here--that we have already done enough by controlling lead in food and gasoline. They argue that we can "coast" the rest of the way and that childhood lead poisoning will eventually disappear by itself without further actions. Paradoxically, these parties also argue that while needed, addressing paint hazards will cost too much, despite the cost-benefit studies demonstrating that the nation would save billions of dollars through effective prevention.

Paint lead is the final widespread high dose source of childhood lead exposure left in this country, and the source responsible for inflicting harm on nearly one-tenth of all children one to five years old. This report makes it clear that there is no longer any excuse for waiting for further study before taking action. We know enough now to implement rational, careful, scientifically-supportable policies, programs, and laws that will make lead poisoning a relic of the 20th century.

We are grateful to the Fannie Mae Foundation for its support of this project.

Dave Jacobs, CIH
Deputy Director, National Center for Lead-Safe Housing
February 28, 1995

Executive Summary

Deteriorated lead-based paint, house dust and soil are considered the most significant sources and pathways of lead exposure for children in the United States (CDC, 1991). Thus, current lead hazard control strategies address deteriorated paint, soil and dust lead levels to reduce them to acceptable levels.

Based on the empirical evidence from numerous research projects described in the literature, it can be shown that a broad range of hazard control strategies can eliminate or control the sources of lead and bring household dust-lead levels down to the clearance levels established by the United States Department of Housing and Urban Development (HUD). Furthermore, studies also show declines in blood lead levels following hazard control. The published evidence is summarized in Tables A and B below and analyzed later in this report.

Table A. The Long-Term Effect of Lead-Based Paint Hazard Control as Measured by Dust Lead Levels.

	Baltimore traditional (Farfel, 1990)	Baltimore modified traditional (Farfel, 1990)	Baltimore experimental (Farfel, 1991) *	Baltimore follow-up (Farfel, 1994a)*
Intervention (using the Title X definitions)	Interim control without comprehensive clean-up	Interim control without comprehensive clean-up	Abatement	Abatement
Year of intervention	1984-85	1984-85	1986-87	1988-91
Number of dwellings	44	15	6	13
Duration of follow-up	6 months	6 months	6 - 9 months	1.5 - 3.5 years
Geometric mean dust lead loading (µg Pb/ft²) by surface type:				
Floors:				
pre-intervention	251	288	520	251
at follow-up	316	316	56	37
% change at follow-up	26% increase	10% increase	89% decrease	84% decrease
Windowsills:				
pre-intervention	1,338	1,803	4,610	1,041
at follow-up	1,543	1,636	409	102
% change at follow-up	15% increase	9% decrease	91% decrease	90% decrease
Window troughs:	†	†		
pre-intervention	15,504	18,283	29,437	14,221
at follow-up	12,474	24,892	1,004	604
% change at follow-up	20% decrease	36% increase	97% decrease	96% decrease

* Although these abatements were conducted before the HUD interim guidelines were issued in 1990, the abatements were comprehensive and include many of the guidelines provisions for worker protection, containment and clean-up.

† The traditional and modified traditional procedures did not address lead paint hazards in window troughs.

Table B. The Long-Term Effect of Lead-Based Paint Hazard Control as Measured By Blood Lead Levels.

Intervention title (years implemented)	Duration of follow-up	Percent of children having follow-up in each study	Number of children in each study group	Source of lead targeted for hazard control*	Mean blood lead levels (µg/dL)		
					Pre-intervention	Decline at follow-up	Percent decline in blood lead level at follow-up
Baltimore traditional vs. modified (1984-85)	6 months post intervention	19%	29	paint	32.5	1.9	6%
Baltimore dust control (1981-82)	†	63%	14 35	dust no treatment	38.6 38.5	6.9 0.7	18% 2%
Boston Retrospective (1984-85)	8 months post intervention	52%	59	paint	35.7	10.2	29%
St Louis Retrospective (1989-90)	10-14 months post diagnosis	28%	37 17	paint no treatment	35 35	8.2 4.2	23% 12%
Worcester County retrospective (1987-90)	up to one year post intervention	68%	132	paint	25.9	4.8	18%
New York chelation (1989-91)	6 months post intervention	>90%	87	paint	27	6 §	22%
Boston three-city soil (1989-90)	11 months post intervention	98%	52 51 47	soil, dust, paint dust, paint paint	13.1 12.4 12.0	2.44 0.91 0.52	19% 7% 4%

* All of the paint hazards were treated with interim control procedures to stabilize paint hazards. The only study that fully abated a lead hazard was the Boston three-city soil study, where soil hazards were addressed.

† The cleaning was done twice per month for a 12 month duration, with concurrent follow-up

§ All the children in the New York study received provocative chelation, but did not undergo chelation treatment.

Lead hazard control strategies must be carried out carefully and must generally follow the practices described in the 1995 version of the *HUD Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* (HUD, 1994a). If hazard control practices are conducted haphazardly by untrained workers and contractors, dust lead levels will likely increase inside the dwelling and may be difficult to clean to acceptable levels.

Practices, such as extensive dry scraping or sanding, open flame burning, uncontrolled power sanding, sand blasting, or water blasting of lead painted surfaces, create large amounts of leaded dust which can cause lead poisoning of workers and occupants. Studies show also that these practices make effective clean-up very difficult. Worker and occupant protection precautions, including sealing off work areas and properly covering floors, furniture, radiators and vents, must also be taken because leaded dust will be generated by the lead hazard removal procedures. These precautions are necessary:

1) to avoid poisoning workers,
2) to avoid contaminating the furnishings and the area outside the work environment, and
3) to facilitate clean-up efforts.

Careful and thorough clean-up is necessary to ensure that dust generated by the lead hazard removal procedures themselves are controlled and that dust lead levels are acceptable for reoccupancy of the dwelling.

The only way to determine that surface dust lead levels are acceptable is to collect dust samples, which should be analyzed in an EPA-recognized laboratory to ensure the results are reliable. Dust lead measurements cannot be made with the naked eye. Surfaces that appear equally dusty can have drastically different levels of leaded dust on them. All of the current research studies that are examining the efficacy of lead hazard control work are relying heavily on the results from dust sampling. Visual appearance alone will not suffice to determine if one of the most significant lead exposure sources for the majority of children, leaded dust, has been reduced to acceptable levels.

If interior and exterior painted surfaces are stabilized, underlying causes of paint deterioration are corrected, horizontal surfaces are made smooth and cleanable, and dust lead levels on those surfaces are brought down to acceptable levels, it is likely that lead dust levels can be kept at acceptable levels over time with normal housekeeping and maintenance practices. But further study is needed to determine what the most cost-effective hazard control treatments are and for how long the dust lead levels are likely to continue to be acceptable. Studies are also needed to determine what levels of maintenance are needed to prevent reaccumulation of excessive levels of lead in household dust after particular lead hazard control strategies have been implemented. It is likely that the necessary level of maintenance will vary depending on several factors, including the hazard control strategy used and the levels of lead in exterior dust and soil. Currently, there are many ongoing research studies, most of which are funded by HUD, the Environmental Protection Agency (EPA), and the Centers for Disease Control and Prevention (CDC), that are designed to answer these questions.

1. Introduction

Childhood lead poisoning is a pervasive problem in the United States, with 1.7 million young children (8.9%) having more than 10 µg/dL of lead in their blood (Brody, 1994, Pirkle 1994). The Centers for Disease Control and Prevention and the American Academy of Pediatrics have established a blood lead level of 10 µg/dL as the indicator of adverse health effects, including reduced intelligence and neurobehavioral problems. Empirical evidence shows that housing-associated lead hazards are responsible for most childhood lead poisoning cases in the United States (CDC, 1991). In fact, lead-based paint is considered the most common source of high-dose lead poisoning among children in the U.S. (ATSDR, 1988). Title X of the *Housing & Community Development Act* defines "lead-based paint hazards" as any condition that causes childhood lead exposure from lead-contaminated dust or soil, or from lead-contaminated paint that is deteriorated or present in accessible, friction, or impact surfaces, and that would result in adverse human health effects (Title X, 1992). Since Congress passed Title X, researchers, regulators, and practitioners from the Federal government, state and local governments, and the private sector, have made great strides in developing the science, facilities, equipment, and expertise needed to reduce housing-associated lead hazards on a national scale.

It is generally believed that the most effective means of controlling housing-associated lead hazards is to identify the likely sources of lead on a case-by-case basis and carefully remove or control them. Numerous environmental interventions have been developed to control potential lead hazards in paint, soil, and dust (HUD, 1994a). Hazard control procedures and requirements vary widely and range from those that involve fairly complete lead removal or enclosure (abatement), to more limited hazard control strategies (interim controls) that require, for example, treating and repainting only those surfaces with peeling, chipping, or deteriorating lead-based paint. Rigorous cleanup follows both abatement and interior controls.

Although public health officials have recommended lead hazard control for the treatment of lead-poisoned children for more than forty years, there have been relatively few studies designed to evaluate the short- and long-term efficacy of these efforts. While it seems obvious that safely controlling housing-associated lead hazards should be more effective in preventing childhood lead poisoning than doing nothing at all, the scientific data to evaluate this intuition can only be obtained by thoroughly reviewing the literature. There is no single study or source of information that fully addresses this complex issue.

The primary objective of this report is to comprehensively review the literature and to describe and synthesize what is currently known about the short- and long-term efficacy of environmental interventions to control housing-associated lead hazards. Beginning with the premise that effective interventions are needed to reduce the prevalence of childhood lead-poisoning, researchers and policymakers should recognize the gaps in our knowledge and understand what is already known.

1.1 Overview of This Report

This report critically reviews the available research studies, as well as data collected from selected on-going lead hazard control programs. Some of these studies were designed to measure the efficacy of environmental interventions, while others were not.

Section 2 provides an overview of children's lead exposure pathways, and discusses past and current lead hazard control practices.

Section 3 discusses issues related to measuring the efficacy of lead hazard control interventions. The section notes that all of the published studies on the subject evaluate the impact of interventions on already lead-poisoned children, which is an evaluation of secondary prevention. The impact of interventions on primary prevention, or preventing non-poisoned children from becoming lead poisoned, is not known and may be different than observed for already poisoned children. In addition, the section discusses the benefits and limitations of using dust or blood lead levels to evaluate the effectiveness of the interventions.

Section 4 provides definitions of terms used throughout this report. Since the terminology for abatement and lead hazards has changed over time, it is important to categorize the intervention used in past studies using the current terminology, and not simply use the terminology used in the manuscript. In addition, this section provides a definition of efficacy which is used to summarize the information provided by each study.

Section 5 describes a framework for summarizing each of the environmental and secondary prevention intervention studies that provide information to evaluate the effectiveness of housing-related lead hazard control activities. The interventions target the control of lead hazards in paint, dust, and/or soil. In each case, the study's objectives, methods, results, and conclusions are described and the implications of the findings and potential sources of bias are discussed.

Section 6 provides a limited assessment of potential sources of information from selected hazard control programs.

Section 7 provides a brief description of current research designed to measure intervention efficacy.

Section 8 summarizes the findings in Sections 5, 6, and 7 and includes summary tables.

Section 9 outlines future research needs.

Section 10 provides conclusions based on all of the previous sections.

Section 11 contains all references.

2. Overview of Lead-Based Paint Hazards in Housing

Residential lead-based paint has been sold in the United States for more than two hundred years (EDF, 1992). For the last 90 years, considerable evidence has accumulated to indicate that lead-based paint is a major source of childhood lead poisoning. Congress passed the *Lead-Based Paint Poisoning Prevention Act* in 1971 in an attempt to alleviate the hazards associated with lead-based paint (U.S., 1971). In 1978, the Consumer Products Safety Commission (CPSC) banned the addition of lead to interior and exterior residential paint (CPSC, 1977). In the 1987 and 1988 amendments to the *Lead-Based Paint Poisoning Prevention Act*, Congress directed the Department of Housing and Urban Development (HUD) to develop comprehensive and workable plans for the cost-effective inspection and abatement of lead-based paint in both public housing and privately-owned housing. As part of this directive, HUD was required to estimate the amount and characteristics of housing that contain lead-based paint and, in response, the agency sponsored a national survey of lead-based paint in housing (Clickner, 1992). In December 1990, HUD submitted to Congress a *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately-Owned Housing* (HUD, 1991a) based on that survey.

The Comprehensive and Workable Plan stated that an estimated 57.4 million homes, representing 74 percent of all occupied housing units built before 1980, contain lead-based paint somewhere in the building. The study further determined that approximately 71 percent of all pre-1980 housing units occupied by families with young children contain lead-based paint. In an estimated 3.8 million units nationwide, children are potentially exposed to non-intact leaded paint or to high dust lead levels (HUD, 1991a).

2.1 Children's Lead Exposure Pathways

Ingestion of lead-contaminated house dust is thought to be the primary cause of childhood lead poisoning in the U.S. (CDC, 1991). Many children live in dwellings with high dust lead levels and routinely put dust-laden fingers, toys, and other objects into their mouths. Deteriorated or disturbed lead-based paint is a major internal (inside the residence) source of leaded dust and may give rise to relatively high risks of both acute and chronic lead poisoning. Leaded dust may also be tracked or blown into a residence from soil and external dust that is contaminated primarily by lead-based exterior paint and/or leaded gasoline used in the past (EPA, 1991). Lead-based paint, soil, and external dust contribute directly to a child's blood lead level if ingested. However, a more common scenario appears to be the contamination of house dust by these sources and the child's subsequent ingestion of the lead-contaminated dust (CDC, 1991).

In 1973, Needleman and Scanlon hypothesized that unintentional ingestion of house dust could be a significant source of lead in children (Needleman, 1973). In 1974, Vostal and Sayre conducted research to test the hypothesis that lead-containing house dust caused increased lead exposure of inner city children (Vostal, 1974; Sayre, 1974). Other studies followed and today it is accepted that, as exterior lead-based paint deteriorates or is disturbed, it contaminates soil and finds its way into a dwelling in the form of dust. Further, interior lead-based paint contributes in various ways to surface dust. The principal pathway of childhood lead exposure for most children is thought to be from lead-based paint and soil to house dust to hands or other objects and, finally, to ingestion (Bornschein 1985; Duggan 1985; Bellinger 1986).

The type and condition of housing is also predictive of children's blood lead levels. One study, which characterized five housing categories, found that over one-half of the blood lead variability in 18-month-old children was due to housing type and condition (Clark, 1985). The authors found that children living in deteriorated pre-World War II housing had significantly higher blood lead levels than children living in public, rehabilitated, or pre-WWII housing in satisfactory condition. Another study that followed children who were treated for lead poisoning and released back into different home environments found that the children's blood lead levels decreased during the year following diagnosis in a pattern consistent with Clark's findings (Chisolm, 1985). Chisolm observed a larger blood lead level decrease in children released to newer housing in good condition than in children released to older deteriorated housing. Presumably, the children released to the older housing continued to be exposed to loose paint and high dust lead levels.

2.2 Renovation, Remodeling, Abatement, and Lead Poisoning

The presence of lead-based paint in housing is a potential hazard to children not only when it deteriorates into dust, but when it is disturbed for renovations, remodeling, or abatement. The literature on this subject contains numerous case reports of children who were poisoned after these activities (Wolf, 1973; Rabinowitz, 1985; Curran, 1989; Marino, 1990; Shannon, 1992; Rey-Alvarez, 1987; Feldman, 1978). In most cases, the probable cause of the poisoning was the lack of knowledge about safe work practices and the potential hazards of leaded dust.

Over 20 years ago, the hazards associated with renovation and lead paint hazard control activities were noted. In 1973, Wolf wrote that "within the past two years, lead poisoning has been diagnosed in the children of two families involved in the restoration of their home." The first family conducted extensive renovation, while living in the home, that included burning and scraping old paint. "Aware of the risk of lead poisoning, the mother had the children's blood lead levels checked on several occasions during the remodeling. At first low, the [blood] lead concentrations increased" and one child had to be hospitalized. The children of the second family were kept out of the house for one week so that work could proceed at a faster pace. Two weeks after the family returned, the children's blood lead levels increased to toxic levels and they were hospitalized and treated for lead poisoning. Dust samples collected from between the floorboards in the house showed a lead content greater than 1 percent (>10,000 µg/g). Although dust samples were not collected before abatement -- and, therefore, a definite conclusion cannot be drawn -- it is likely that the restoration work contaminated the house dust with lead. It is further plausible that the dust was not cleaned up adequately before the children were allowed to move back home and thus, their blood lead levels increased (Wolf, 1973).

More recent studies have shown that the process of uncontrolled abatements continue to be associated with increases in blood lead levels. In 1985, Rabinowitz et al. published a 2-year longitudinal study of 204 children. They observed that refinishing activities in the presence of lead-based paint were associated with a statistically significant increase in blood lead levels. The authors conclude that young children residing where lead paint is being resurfaced may be at special risk of increased lead exposure (Rabinowitz, 1985). Curran and Nunez describe a case study whereby a two-and-a-half-year-old boy was found to have a blood lead level of 79 µg/dL following extensive renovations in his home. The renovations included demolition and replacement of most of the walls and plumbing, which generated large quantities of dust (Curran, 1989). Marino et al. describe a series of four cases of childhood lead poisoning during renovation of a rural farmhouse (Marino, 1990). Shannon and Graef found that household renovation was the most common source of lead poisoning in 50 infants, aged 12 months or younger, enrolled in their clinic (Shannon, 1992). Finally, Rey-Alvarez and Menke-Hargrave document 13 case studies that illustrate the importance of vacating dwellings during the deleading process. They found that blood lead levels of already lead-poisoned children increased even further following the lead hazard reduction activities which were initiated for the benefit of that child (Rey-Alvarez, 1987).

Finally, lead dust hazards may extend beyond the home being renovated, and may affect the renovator's home. Feldman highlighted this concern when he wrote:

> *A new industrial hazard has been developed in the attempt to delead old houses...serious problems may result from careless or inexperienced deleading practices. In addition to the hazards of the jobsite, the deleader may carry with him on his skin, hair, and clothing sufficient lead in paint and dust particles to continue his own exposure off the job and to contaminate his family members (Feldman, 1978).*

Many cases of child (and adult) lead poisoning occurred from renovation and remodeling activities in the past and probably continue today where homeowners and untrained contractors disturb leaded surfaces. Furthermore, traditional practices of abating residential leaded paint have been associated with acute increases in levels of lead in house dust and the blood of children and workers (Chisolm, 1985; Farfel, 1991). The use, in the past, of lead abatement procedures that are today considered dangerous probably caused numerous undetected cases of lead poisoning. Paint removal methods such as open flame burning or torching, machine sanding, grinding, or abrasive blasting without special local exhaust controls, uncontained hydro-blasting or high pressure water wash, and heat guns operated above 1,100 degrees Fahrenheit have been shown to produce high airborne lead levels that may poison workers and contaminate dwellings with excessive amounts of lead dust (NIOSH, 1992; Jacobs, 1991; Rekus, 1988; Amitai, 1991; Fischbein, 1981; Farfel, 1990 and 1991). The Department of Housing and Urban Development and several states banned the use of a number of these methods for residential lead abatement because of the hazards they pose (HUD, 1994a). The EPA, which has produced an educational pamphlet on remodeling and renovation for homeowners, also discourages the use of these methods (EPA, 1994).

In addition to the direct hazards generated by specific abatement methods, lack of thorough cleanup, improper disposal of debris, inadequate worker and occupant protection, and contamination of furnishings with leaded dust was typical during traditional practices for abatement of residential lead-based paint (Chisolm, 1985;

Farfel, 1990). Today, innovative abatement and interim control methods have been developed to "safely" abate and control housing-associated lead hazards. The next section discusses some of these methods.

2.3 "Safe" Lead Hazard Control Practices

Lead abatement and interim control activities are generally not "safe" and should be performed only by trained personnel under controlled situations. However, numerous techniques have been developed in recent years to decrease both the risk of high dose lead exposure among workers, and the likelihood that leaded dust will contaminate the dwelling and its furnishings.

Removal methods have been designed to permanently control lead hazards without releasing large quantities of dust into the environment. These methods are described in the 1995 version of the HUD *Guidelines for The Evaluation and Control of Lead-Based Paint Hazards in Housing* (HUD, 1994a). The recommended control methods include:

- wet scraping techniques
- building component replacement
- heat guns operating below 1,100 ° Fahrenheit
- power sanders with high efficiency particle accumulator (HEPA) exhaust filters
- HEPA vacuum blasting equipment
- HEPA vacuum needle guns
- certain chemical removal methods

Structural enclosure methods and building component replacement are also abatement techniques that do not typically release uncontrolled leaded dust or fumes, unless heavy demolition is involved (HUD, 1994a).

While abatement is designed to make dwellings lead-safe by permanently controlling lead hazards, interim controls are designed to temporarily control lead hazards. Interim control activities include a combination of:

- stabilizing paint
- removing dust
- creating cleanable surfaces
- covering bare soil
- controlling lead hazards on friction, impact, and child-accessible surfaces

A combination of interim controls and limited abatement is often utilized as a cost-effective approach to reducing lead hazards. Conducting abatements when a dwelling is vacant or undergoing renovation (opportunistic abatement) may be the most cost-effective approach (HUD, 1994a).
For the purposes of this report, the term "hazard control" includes both abatement and interim controls. Local definitions of abatement are likely to differ from the way it is used here.

Regardless of the method(s) used, however, neither abatement nor interim control measures can be considered "safe" until the dwelling has been thoroughly cleaned and has passed clearance testing. Since most lead hazard control work generates some leaded dust, and since previous studies have indicated that cleaning can be accomplished if done carefully (HUD, 1991b), it is necessary for all lead hazard control activities to adhere to clearance procedures. Clearance testing, which involves visual inspection and environmental sampling by a trained certified professional, ensures that the lead hazard control work was actually completed as specified; the area is safe for unprotected workers to enter; and the area is safe for residents and young children to live in (HUD, 1994a).

The literature suggests that deteriorated or disturbed lead-based paint constitutes a major source of leaded dust in residential environments and that children are commonly exposed to the lead through normal hand-to-mouth contact. Uncontrolled removal of old paint and inadequate cleanup has caused numerous cases of child and adult lead poisoning in the past. Today, methods to safely remove or treat leaded surfaces exist and dust clearance procedures are standardized and feasible. This ensures that children do not move back into dwellings contaminated with lead by the treatment process itself. However, it is important to know which methods are most effective in controlling lead hazards in the home over the short- and long-term. The following sections present numerous studies to illuminate our current state of knowledge on this subject.

3. Measuring the Impact of Lead Hazard Control Interventions

While each study contributes to our understanding of the impact of lead hazard control interventions, each study has strengths and limitations that influence the interpretation of the findings. Before reviewing the studies, it is important to understand the difference between the primary and secondary prevention of lead poisoning, and some of the problems with using blood or dust lead levels to measure the effect of lead hazard control activities.

3.1 Primary Versus Secondary Prevention of Lead Poisoning

Except for one EPA study (Weitzman 1993), all of the currently published blood lead studies available measured blood lead levels among *already* poisoned children (above 25 µg/dL) to evaluate the impact of lead hazard control activities. The studies measure the effectiveness of secondary prevention of childhood lead poisoning. The effectiveness of lead hazard control interventions on the primary prevention of childhood lead poisoning may differ. In fact, lead hazard control activities may work better for the primary prevention of lead poisoning among siblings or future residents than as an intervention for already-poisoned children.

Children who are chronically exposed to lead may have large body burdens of lead. The internal lead burdens may slow the reduction of blood lead levels even after a child is moved into a lead-free environment. One study showed that chronically exposed children who were placed in lead-free housing following chelation for blood lead levels of 50 µg/dL or greater had an average blood lead level of 28 µg/dL one year after chelation (Chisolm, 1985). The study highlights that even in a relatively lead-free environment, the blood lead levels of chronically exposed children may not go below 25 µg/dL during the year following diagnosis. However, children born into environments free from lead hazards usually do not have large body burdens of lead. The increase in blood lead levels *prevented* by lead hazard control interventions may be larger than the decrease measured among already-poisoned children.

3.2 Using Dust or Blood Lead Levels as an Outcome Measure

The general assumption behind abatement and interim controls is that by eliminating or controlling the sources of lead in an environment, the dust lead level will be reduced, which will in turn reduce blood lead levels. Therefore, samples of both house dust and blood are typically collected to assess the short- and long-term efficacy of lead hazard control interventions.

It can be argued that lead levels in house dust are a more direct measure of efficacy than are lead levels in blood. Consider the following simplified pathway of lead exposure from a primary lead source (e.g., old paint) to a child's blood.

Lead Source =>	Discharge to Environment =>	Presence =>	Exposure =>	Biological Impact
(old paint)	(deterioration or renovation)	(dust lead level)	(dust-to-hand-to-mouth contact)	(blood lead level)

Sampling house dust for lead provides an estimate of the amount of lead present in the environment. Blood lead sampling provides an estimate of the biological impact of the absorbed dose of lead, after exposure has taken place. Lead hazard control work typically targets the primary sources of lead and/or house dust directly. Therefore, house dust is a more direct measure of efficacy than measuring blood lead levels alone because the presence of lead can be measured before the uncertainties associated with exposure and biological impact occur.

When using dust lead measurements to determine if an intervention is effective in reducing lead-based paint hazards, it is important that dust lead levels are measured both before and after the intervention takes place. Although dust lead levels after an intervention may be below the HUD clearance levels, they may in fact be higher than they were prior to the intervention. Without pre-intervention dust lead levels, this will not be recognized.

Dust lead measurements are also influenced by many factors not associated with lead hazard control interventions. For example, the dust lead loading level, which measures the amount of lead on a surface, is directly affected by the cleaning methods used and the frequency of cleaning in relation to the timing of sampling. In addition, the dust sampling method itself, and the laboratory analysis procedure, may influence estimates of environmental dust lead levels. Standardized dust wipe sampling procedures have been established by the Federal government and ASTM (American Society for Testing and Materials) to minimize the variation in dust lead measurements (HUD, 1994a) (ASTM, 1994). These standardized procedures should be followed by persons conducting efficacy studies.

Measuring a child's blood lead level may show whether the intervention made a difference for the child for whom the intervention was initiated. However, blood lead levels can be influenced by numerous factors that are not associated with the hazard control activities. First, they can be influenced by the levels of lead stored in the bone, which reflect the child's past exposure to lead. Second, they can be influenced by exposure to lead hazards outside the home environment, such as hazards at the home of a relative or babysitter. Third, they can be influenced by behavioral changes that are independent of the environmental changes. For example, as children age, their mouthing behaviors change which may increase or decrease their exposure to the existing lead hazards. Children's blood lead levels tend to peak around two to three years of age. Fourth, they may be influenced by metabolic changes. Finally, blood lead levels may be influenced by seasonal changes which may result from increased exposure to leaded soil or dust, possibly due to opening windows more frequently and playing more out-of-doors during the warmer months of the year. Among 14,033 children screened in Milwaukee from 1990-1994, the average blood lead levels decreased approximately one-third from summer to winter. The seasonal fluctuations were especially keen among children with higher blood lead levels (personal communication, Brad Schultz).

In summary, when the blood lead levels of lead-poisoned children are evaluated over time, the levels can be affected by the season the child was tested, the child's past exposure to lead, the increasing age of the child, as well as any educational or other interventions that coincide with the environmental intervention. Similarly, dust lead measurements can be affected by numerous events not related to the environmental interventions.

4. Definitions

4.1 Definitions of lead hazards, abatement, interim controls

The definitions for lead-based paint hazards and lead hazard control activities have changed over time, which makes it difficult to compare studies. For example, studies published in the early 1980's used the term "abatement" to describe the crude procedure of scraping and repainting surfaces covered with deteriorated leaded paint. The following definitions, which were published in Title X of the *Housing and Community Development Act of 1992* (Title X, 1992), are used throughout this report to standardize the terminology and to help the reader compare the various interventions.

- *Lead-based paint hazards:* any condition that causes childhood lead exposure from lead-contaminated dust or soil, or from lead-contaminated paint that is deteriorated or present in accessible, friction, or impact surfaces, and that would result in adverse human health effects.

- *Abatement:* any set of measures designed to permanently eliminate lead-based paint hazards. The term includes (A) the removal of lead-based paint and lead-contaminated dust, the permanent containment or encapsulation of lead-based paint, the replacement of lead-painted surfaces or fixtures, and the removal or covering of lead contaminated soil and (B) all preparation, clean-up, disposal, and post-abatement clearance testing activities associated with such measures.

- *Interim control:* any set of measures designed to reduce temporarily human exposure or likely exposure to lead-based paint hazards, including specialized cleaning, repairs, maintenance, painting, temporary containment, ongoing monitoring of lead-based paint hazards or potential hazards, and the establishment and operation of management and resident education programs.

The definition of *lead hazard control activities*, as used in this report, includes any physical treatment to a dwelling that results in exposure control. For practical purposes, the activities which comprise abatement and interim control activities can be grouped into the following procedures:

- paint film stabilization
- dust cleaning
- treatment to reduce friction and impact on painted surfaces
- soil covering or removal
- enclosure
- encapsulation
- removal of building components coated with old lead-based paint followed by installation of new construction materials
- stripping of paint using a heat gun, or chemical or contained abrasive techniques, either on or off-site

4.2 Definition of efficacy

Fully evaluating the variety of lead hazard control interventions is complex and ultimately requires considering efficacy, cost, efficiency, aesthetic, and other rehabilitative objectives. For example, the success and widespread applicability of specific interventions is affected by 1) the costs of preparation, remediation, clean-up and clearance testing; 2) the costs of protecting workers and families; 3) profit and overhead; and 4) the costs of waste storage and disposal. Some control methods have other benefits. For example, replacing windows during abatement may improve energy efficiency and meet important rehabilitative objectives, as well as remove a lead hazard.

This report, however, focuses on evaluating only the **efficacy** of lead hazard control interventions, using the following criteria:

(a) **feasibility:** whether the specified procedures are feasible for workers to perform;
(b) **worker protection:** whether workers can be protected from lead exposure and other health hazards;
(c) **containment:** whether, *during* the lead hazard control activities, leaded dust and debris can be contained so that residents are not adversely exposed and areas adjacent to the work area are not contaminated;
(d) **clean-up:** whether leaded dust generated from the activities, once completed, can be cleaned to a reduced level compared to the level prior to the intervention or, alternatively, to a level below the clearance criteria established by HUD; and
(e) **hazard control duration:** whether dust and/or children's blood lead levels can be reduced in the short-term (1 or 2 months) or long-term (6 months or more) after "normal" household activity.

Using this framework, we reviewed each identified study and described the information concerning the efficacy of environmental interventions to control housing-associated lead hazards. Since hazard control duration is not well described in the literature, we focus on this issue. However, information concerning feasibility, worker protection, containment, and clean-up issues is also briefly described when available.

4.3 Definition of Window Trough

Window troughs (formerly known as a window well) are defined as that portion of a window which receives the sash when both the upper and lower ones are down. Typically, this is the area between the storm window and the inner window sash.

5. Review of the Intervention Studies

5.1 Summary of the studies

This section summarizes the environmental intervention studies that provide information on the efficacy of housing-related lead hazard control activities. We identified several studies and demonstration projects that evaluate to varying degrees the effectiveness of housing-related lead hazard control activities (Table 1). The interventions target the control of lead hazards in paint, dust, and/or soil. In Table 1, the type of intervention is listed using the current definitions for "abatement" and "interim control" (Title X, 1992). Each study provides data to evaluate at least one of the following issues that concern the efficacy of lead hazard control activities: cost and feasibility, worker protection, containment, clean-up (immediately post-intervention), and the duration of hazard control. Some of the interventions listed in Table 1 are described and evaluated in more than one publication.

The intervention studies concern lead hazard control activities that occurred over the past 13 years, from 1980 to 1993 (Figure 1). During this time period, HUD published its Interim Guidelines (HUD, 1990) and many states passed specific lead hazard control regulations. Most of the studies reviewed for this report were conducted prior to the newer regulations and thus, evaluated lead hazard control activities that are not currently recommended by the Federal government. However, many of the activities that were evaluated continue to be used today by untrained persons unknowingly disturbing leaded paint.

5.2 Framework for reviewing each study

A framework was developed to categorize the questions addressed by each intervention study; to describe the scientific contribution of each study; and to clarify the gaps in our current knowledge about the short- and long-term efficacy of lead hazard control activities. The following characteristics of each intervention study are described:

- **Objectives**: according to the criteria for evaluating efficacy.
- **The setting**: including a brief description of the lead hazards.
- **Outcome measures** : usually dust, soil, or blood lead levels.
- **Intervention methods and dates** : if the information is available, the specific lead hazard control activities are described.
- **Methods**: described in general terms and by the following design issues:

  - the study design
  - the methods used to select study dwellings (i.e., did the dwelling house a lead poisoned child, contain lead hazards, or was it simply found to contain leaded paint?)
  - the use of a control or comparison group (control groups in these kinds of studies are difficult to construct because it would involve leaving children exposed to a known hazard for research purposes)
  - the duration and completeness of follow-up
  - the environmental sampling procedures

- **Results and conclusions** : concerning the short- and long-term efficacy of the lead hazard control intervention. Results and conclusions concerning feasibility, worker protection, containment and clean-up also are briefly mentioned.
- **Major strengths and limitations** : concerning the data used to evaluate efficacy.

Table 1. Summary of studies that provide information to evaluate lead hazard control activities in housing.

Title of Intervention (including the reports that describe and evaluate the intervention)	Type of lead hazard control intervention evaluated*		Study provides data to evaluate the following issues:			
	Abatement	Interim control	Worker protection	Contain-ment	Clean-up (immediately post-intervention)	Duration of lead hazard control
Baltimore traditional vs. modified study (Farfel, 1990)	no	Paint †	YES	no	YES	YES
Baltimore experimental study (Farfel, 1991)	Paint	no	YES	no	YES	YES
Baltimore follow-up study (Farfel, 1994a)	Paint	no	no	no	YES	YES
HUD/public housing demonstration project (HUD, 1993, 1994) ‡	Paint	no	YES	YES	YES	no
Murphy Homes demonstration project (Jacobs, 1992) ‡	Paint (exterior only)	no	YES	YES	YES	no
HUD/FHA private housing demonstration project (HUD, 1991b) & (EPA, 1992) ‡	Paint	no	YES	YES	YES	no §
Baltimore dust control study (Charney, 1983)	no	Dust	no	no	no	YES
1990 St Louis retrospective study (Staes, 1994)	no	Paint †	no	no	no	YES
Boston retrospective study (Amitai, 1991)	no	Paint †	no	YES	no	YES
Worcester County (MA) retrospective study (Swindell, 1994)	no	Paint †	no	YES	no	YES
New York chelation study (Rosen, 1993)	no	Paint †	no	no	no	YES
Boston three-city soil study (Weitzman, 1993) & (Aschengrau, 1994)	Soil	Dust and Paint	no	no	no	YES

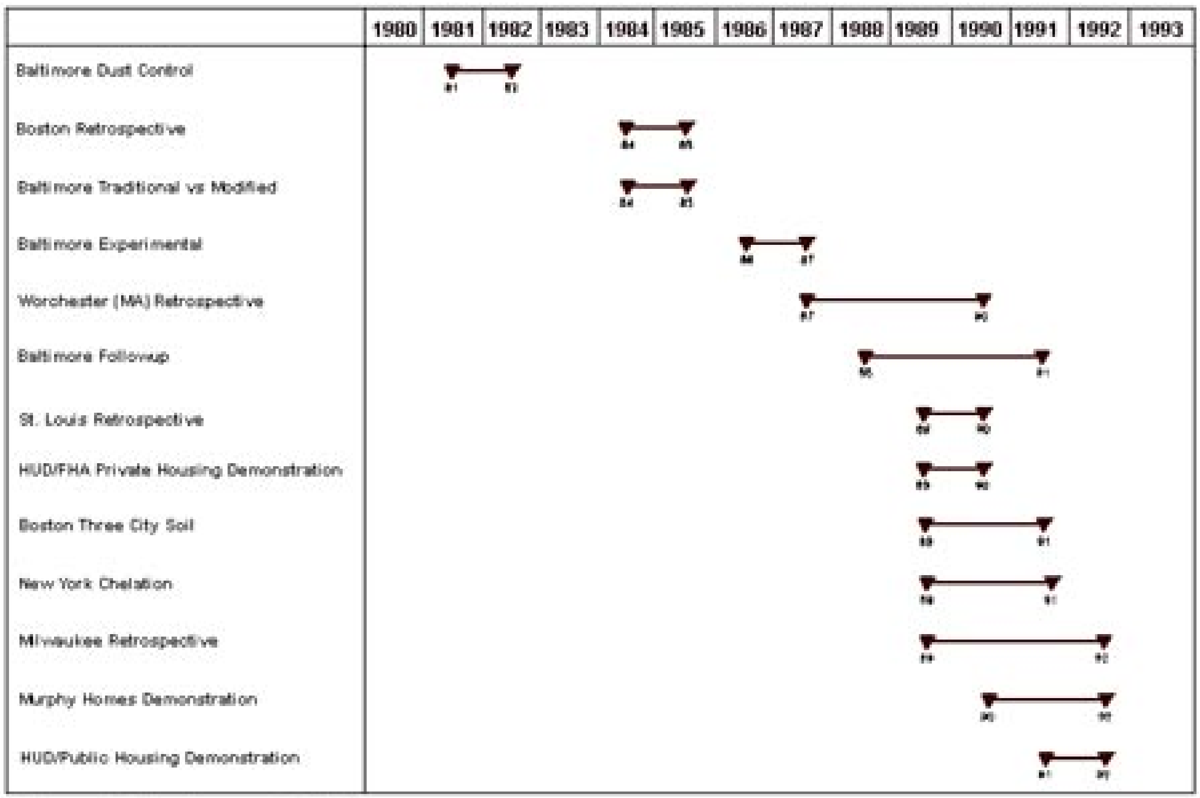
* The interventions are categorized as "abatement" or "interim control" using the *current* definitions reported in Title X, 1992.

† These interim control procedures did <u>not</u> include current provisions for the clean-up of dust hazards following the removal or stabilization of leaded paint.

‡ These demonstration projects also assessed the costs and feasibility of various abatement methods.

§ The CAP study (EPA, 1992) attempts to address this issue but no pre-intervention dust lead levels are available for comparison.

Figure 1: Years during which lead hazard control interventions were implemented for selected studies



Timeline modified from Burgoon et al., 1994

5.3 Environmental intervention demonstration projects

5.3.1 Baltimore traditional/modified study (Farfel, 1990)

Objectives: to evaluate the environmental and health impact of traditional and modified lead hazard control practices. The study addresses several criteria of efficacy: containment, cleanup and long-term hazard control.

Setting: Most of the dwellings were pre-1940 row houses in substandard condition occupied by low-income tenants. All dwellings had multiple interior surfaces coated with lead-based paint and at least one child with a blood lead level >29 µg/dL.

Outcome measurement: venous blood and dust lead levels

Intervention: (1984 and 1985): The intervention consisted of addressing deteriorated paint on surfaces up to four feet from the floor and all paint on easily accessible "chewable" surfaces where the lead content of the paint was >0.7 mg/cm² by XRF, or 0.5 percent by weight using wet chemical analyses. Window troughs were not treated in either the traditional or modified traditional lead hazard control interventions. Table 2 describes the hazard control activities evaluated in this study and in more recent studies conducted by Farfel that are reviewed in the next sections of this report.

Methods:

a. **Design issues:**

study design: observational prospective

method used to select dwellings: it housed a lead-poisoned child

use of a control group: no, two interventions were compared

duration of follow-up: 6 months post intervention

completion of follow-up: Among the 71 dwellings selected because dust lead measurements were available both pre- and immediately post-intervention; 83% of the dwellings in each intervention group were sampled 6 months after the intervention. Among the 151 children in the 71 dwellings, 46 (30%) and 29 (19%) were tested within 1 month and at 6 months after the intervention, respectively, and had not been chelated between the initial and follow-up blood lead measurement.

b. **General methods:** The investigators had no control over the implementation of the interventions. However, they obtained serial measurements of lead in interior surface dust, and analyzed blood lead measurements that were obtained at the discretion of the child's usual health care provider.

c. **Dust sampling strategy and method(s):** Dust wipe samples were collected using a wipe sampling method which is similar, except for the laboratory digestion procedure, to the HUD and ASTM wipe method. Dwellings were sampled three times: pre-intervention; immediate post-intervention; and 6 months post-intervention. Samples were collected from most rooms of each dwelling, with particular attention to areas where children spent most of their time as reported by parents. Follow-up samples were collected from the same rooms and surface types as previous samples.

Table 2. Description of the traditional, modified traditional and experimental abatement practices evaluated by Farfel et al. (Farfel, 1990, 1991, 1994a).*

Abatement Intervention:	Traditional Method (Farfel, 1990)	Modified method (Farfel, 1990)	Experimental method (Farfel, 1991 & 1994a)
Extent of abatement	Up to 4 feet from floor on interior	Up to 4 feet from floor on interior and more	All interior and exterior building components with lead-based paint
Methods	Torch and/or sander	Heat gun	Off-site stripping; on-site caustic stripper; replacement; encapsulation; enclosure
Floor treatments	No	No	Yes - seal or cover
Repainting	No	Yes	Yes
Clean-up	Minimal dry sweep	Standard vacuum and wet scrub	HEPA vacuum and wet scrub
Disposal of debris	Haphazard	Off-site	Off-site
Worker protection	Minimal	Modest	Enhanced by education, training and work practice/engineering controls
Occupant protection †	Minimal	Some	Strict - No home contact during abatement
Protection of belongings	Minimal	Some	Strict - by removal or covering
On-site supervision of workers	Minimal	Yes	Yes

* More detailed information is provided in Farfel, 1991.

† Approximately one-third of the children in both the traditional and modified intervention groups had some contact with the home during the intervention.

Adapted from Table 1 on page 201 (Comparison of traditional, modified traditional, and experimental abatement practices): **Farfel, 1991**. Farfel M.R., Chisolm J.J. *An evaluation of experimental practices for abatement of residential lead-based paint: report on a pilot project.* Environmental Research 1991; 55:199-212.

Results: Dwellings treated by traditional and modified practices had comparable pre-intervention dust-lead loading levels. Smooth surfaces tended to have the lowest lead loading values and loadings were highest in the spring and summer. Prior to intervention, surface type and season were significant predictors of dust lead levels.

Immediately post-intervention, the lead loading levels in dwellings treated by modified practices were significantly lower than the levels in dwellings treated by traditional practices (see Table 2 for a description of the practices). Among the dwellings treated by traditional practices, lead loading levels measured immediately post-intervention were typically 10 to 100-fold greater than the pre-intervention levels on windowsills and on floors near treated surfaces. Among the dwellings treated by modified practices, lead loading levels were similar prior to and immediately post-intervention, and most treated surfaces remained above the "target" value of 139 µg/ft² (1.5 mg/m²) even after final clean-up. Neither traditional nor modified practices treated window troughs, and lead loading levels in troughs remained high immediately following intervention for both groups of dwellings.

At 6 months post-intervention, lead loading levels were similar to, or greater than, their respective pre-intervention levels in both groups of dwellings. These results are further summarized in Section 8.2.1, Table 11.

Among the 46 children with blood lead measurements obtained within 1 month following the intervention, the geometric mean blood lead level 1) increased from 36.9 to 43.7 µg/dL among the 27 children whose dwellings underwent the traditional methods; and 2) increased from 34.4 to 35.4 µg/dL among the 19 children whose dwellings underwent the modified methods. Among the 29 children (only 19% of the study population) with blood lead measurements available 6 months after the intervention, the authors combined the two intervention groups and reported that the geometric mean blood lead level decreased only slightly from 32.5 to 30.7 µg/dL.

Major strengths: Long-term efficacy of the interventions can be assessed since a high proportion (83%) of dwellings had dust lead measurements available after 6 months of "normal" use.

Major limitations: A low proportion of children had follow-up blood lead measurements that met the criteria for analysis: they were obtained by the health care provider but did not follow chelation therapy (30% within a month; 19% at 6 months). Since the study uses follow-up measurements obtained at the health care provider's discretion (48% of the children did not have follow-up measurements obtained by their health care provider), the intervention's effect on blood lead levels may be underestimated. Children with poorer outcomes may be more likely than those with better reductions in blood lead levels to have follow-up measurements obtained by their health care provider (Staes, 1994), which may underestimate the intervention's effect. Then again, by excluding measurements that followed chelation, which is appropriate, the intervention's effect may be overestimated. Finally, the authors did not account for the impact of seasonality on the blood lead measurements obtained six months after the intervention.

Conclusions: Traditional lead hazard control activities resulted in acute increases in dust lead loading levels and in the blood lead levels of children. The modified methods were less likely to exhibit these acute increases. However, neither intervention resulted in any long-term reductions in house dust lead loading. The long-term efficacy of the interventions may have been limited for several reasons: 1) the procedures were limited, 2) some children had contact with the home while the intervention was underway, and 3) the intervention did not address high-dose sources of leaded dust in window troughs and thus left the potential for ongoing exposure to lead in paint and dust. Poor containment and clean-up practices may also have contributed to increased and ongoing exposures to leaded dust on upholstered furnishings and in air ducts and vents. It is difficult to interpret the reported blood lead data given the low proportion of children with follow-up data.

5.3.2 Baltimore experimental study (Farfel, 1991)

Objectives: To evaluate experimental lead hazard control practices that were designed to minimize lead exposure to workers, occupants and the environment. The study addresses worker protection, clean-up, and long-term hazard control.

Setting: The dwellings were poorly maintained, but structurally sound, row houses located in the City of Baltimore. The dwellings were built in the 1920's and had multiple lead paint hazards. The dwellings included in this study were similar in age, condition, and type to dwellings included in a previous study (Farfel, 1990).

Outcome measurement: dust lead levels

Intervention: (1986 and 1987): The intervention addressed lead-based paint identified by trained inspectors on all interior and exterior surfaces where the lead content of the paint exceeded 0.7 mg/cm² by XRF or 0.5 percent by weight by wet chemical analysis. See Table 2 in the previous section for a description of the lead hazard control activities that comprise the experimental intervention.

Methods:

a. Design issues:

study design: prospective (pilot project)

method used to select dwellings: four vacant dwellings that contained lead paint hazards had renovations planned; two dwellings housed a lead-poisoned child

use of a control group: no (however, since this was a longitudinal study, each house served as its own control)

duration of follow-up: 6 to 9 months post-intervention

completion of follow-up: 100%

b. General methods: Six dwellings were identified that were structurally sound, but contained lead paint hazards. The abatement work was conducted by one abatement contractor. The contractor first performed the demolition and on-site paint removal work. Then they cleaned the work area so workers from other trades could complete their renovation work safely. Lastly, they did a final clean-up after all renovation was complete and prior to reoccupancy.

The abatement workers received training in occupational safety and health issues and were provided with protective equipment. Before starting the work, employees had their blood lead levels measured. Workers with blood lead levels greater than 20 µg/dL were excluded from abatement work. Periodic follow-up blood lead measurements were obtained as part of the worker protection program.

c. Dust sampling strategy and method(s): Sampling and analytical techniques for lead in dust were done by the methods of Vostal et al. (1974) with modifications as previously described (Farfel, 1990). Serial measurements of lead loading in interior dust on household surfaces were made immediately pre-abatement, during abatement, after the final cleanup, and 1, 3, and 6 to 9 months post-abatement. Dust wipe samples were collected from the same rooms and surfaces over time.

Results: Prior to abatement, the geometric mean dust lead loading level was highest on window trough surfaces, followed by windowsills and then floors (Table 3). Following clean-up, the mean dust lead loading level on these surfaces was significantly lower than was observed prior to the abatement, and similar low levels were measured as long as six to nine months after the abatement had been completed.

Figure 2 also illustrates the geometric mean dust lead loading over time by surface type and by abatement method. The increase in dust lead loading after abatement, but prior to painting windows or sealing floors, indicates that lead hazard control activities should include provisions for the containment of dust created by the activity itself, and the protection of workers, furnishings and the occupants until dust lead levels can be reduced, following clean-up. (The data point marked "?" for window sills is missing in the manuscript because the components were located off-site and could not be tested.) Figure 2 also illustrates that the occupants of the dwellings were able to continue to further reduce dust lead loading on the floors after clean-up. Presumably, the floors were smooth and cleanable after either sealing them with polyurethane or deck enamel, or covering the floor with vinyl tile. The dust lead loading in the window troughs of new windows was much lower than dust lead loading in windows stripped using an on-site caustic paint removal method.

Although the data to evaluate worker protection is limited, the authors report that three workers (who worked on two to four of the dwellings) had initial blood lead levels between 15 and 20 µg/dL and follow-up levels that did not exceed 22 µg/dL.

Major strengths: Dust lead measurements were obtained in a systematic manner to illustrate the changes in dust lead loading both during the abatement process and during the months following abatement. Since the housing studied in this study is similar in age, condition, and type to a previous study (Farfel, 1990), the interventions and their outcome can be compared.

Major limitations: There is inadequate data to fully evaluate the worker's blood lead levels and, thus, worker protection issues.

Conclusions: The experimental abatements resulted in significant reductions in house dust lead levels which persisted during the 6 to 9 months of follow-up.

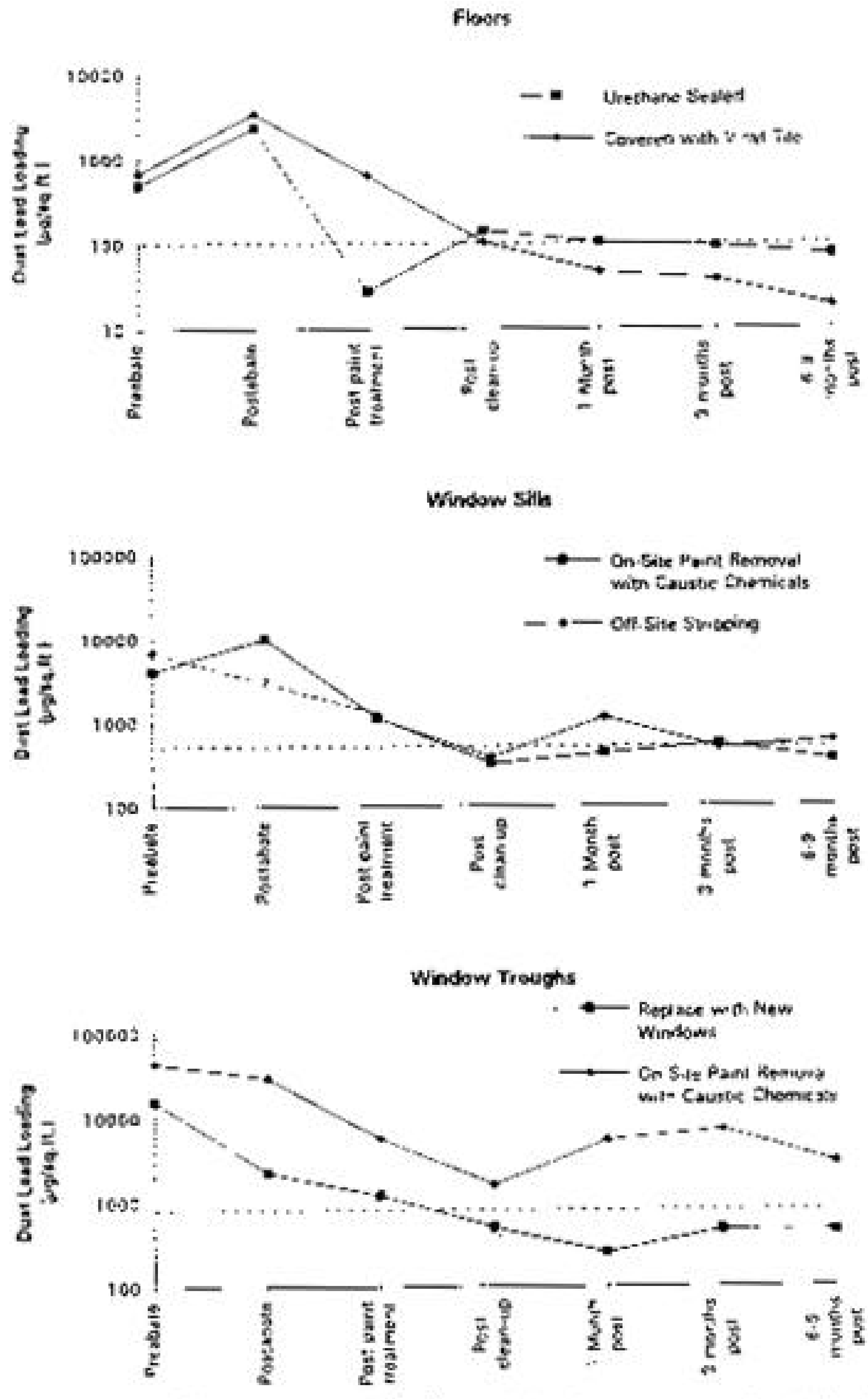
Table 3. Geometric mean dust-lead levels (µg/ft²)*, over time in dwellings that underwent experimental abatement, by type of surface, Baltimore, 1986-87 (Farfel, 1991)

Surface type:	Pre-abatement dust lead level (µg/ft²)	Post-abatement dust lead level (µg/ft²)	
		after clean-up	6-9 months
Floors			
Geometric mean	520	130	56
95% confidence interval	(390, 697)	(102, 177)	(46, 74)
Number	70	70	63
Windowsills			
Geometric mean	4,610	325	409
95% confidence interval	(3,021, 7,027)	(195, 558)	(242, 669)
Number	34	35	31
Window troughs			
Geometric mean	29,437	939	1,004
95% confidence interval	(18,069, 47,962)	(567, 1,562)	(548, 1,850)
Number	28	31	24

* To convert to mg/m², divide the value for µg/ft² by 92.95.

Adapted from Table 2 on page 203 (Geometric mean (GM) dust-lead levels (mg/m²) over time in experimental dwellings by type of surface): **Farfel, 1991**. Farfel M.R., Chisolm J.J. *An evaluation of experimental practices for abatement of residential lead-based paint: report on a pilot project.* Environmental Research 1991; 55:199-212.

Figure 2: Geometric mean dust lead loading levels over time by surface type and abatement method. Baltimore, 1986 to 1987 (Farfel, 1991). (The horizontal dotted lines indicate the current HUD clearance standards)



Adapted from Figure 1 on page 204 and Appendix A on page 210 in Farfel M.R., Chisolm J.J. An evaluation of experimental practices for abatement of residential lead-based paint: report on a pilot project. Environmental Research 1991, 55:199-212

5.3.3 Baltimore 1.5 - 3.5 year follow-up study (Farfel, 1994)

Objectives: To evaluate the long-term changes in dust lead levels in dwellings that underwent comprehensive abatement practices.

Setting: The condition (mostly substandard), age (pre-1940) and type (row house) of dwellings included in this study was similar to those included in the previous studies (Farfel, 1990, 1991) (Mark Farfel, personal communication).

Outcome measurement: dust and soil lead levels

Intervention: (1988 to 1991): The interventions were conducted in compliance with the Maryland regulations (COMAR, 1988) in place at the time. In general, the interventions consisted of the following features: fixing water leaks and other impediments to abatement; treating all lead painted surfaces primarily using replacement and enclosure methods and minimal on-site paint removal; installing vinyl replacement windows; making floors smooth and easily cleanable; and clean-up with wet washing and HEPA vacuums. The lead hazard control activities (described in Table 2) are similar to the HUD interim guidelines (HUD, 1990) in their effort to ensure adequate containment, worker protection and clean-up.

Methods:

a. **Design issues:**

study design: prospective

method used to select dwellings: dwellings had been previously abated according to Maryland regulations (COMAR, 1988) because it housed a lead-poisoned child

use of a control group: no (however, since this was a longitudinal study, each house served as its own control)

duration of follow-up: 1½ to 3½ years after abatement

completion of follow-up: Among the 63 dwellings abated according to Maryland regulations between 1988 and 1991, 13 (20.6%) were selected.

b. **General methods:** Dwellings were eligible if the occupants consented, no major renovations had occurred since the abatement, and there were at least six pairs of pre- and immediately post-abatement dust lead measurements obtained from the same floor and window locations at each time period. The condition of the abated surface was assessed and dust wipe and composite soil lead samples were obtained.

c. **Dust sampling strategy and method(s):** Dust wipe samples were collected in study dwellings during December, 1991 and January, 1992. The number of samples per dwelling ranged from four to six for floors and windowsills and two to five for window troughs. Where possible, dust samples were collected from the same surfaces that had been sampled pre- and immediately post-abatement. Sample collection and analysis was done by the same methods used earlier (Farfel, 1990, 1991).

Results: The authors report that the geometric mean dust lead levels 1½ to 3½ years post-abatement were significantly lower than both the pre- and immediately post-abatement levels (Table 4). Dust lead loadings at this extended follow-up were only 16, 10, and 4 percent of pre-abatement levels for floors, windowsills, and window troughs, respectively. Modelled estimates of the change in dust lead levels are described in Table 5. Despite some reaccumulation of lead in dust, 78 percent of all dust lead loading measurements remained within Maryland's interim post-abatement clearance standards. Over half (21/39) of the dust lead readings above the clearance levels at extended follow-up were from window troughs. Three of four window troughs abated by caustic chemicals had the highest lead loadings (ranging from 11,619 µg/ft² to 15,058 µg/ft²) 1½ to 3½ years after abatement.

The abatement treatments were found to be intact and in good condition 1½ to 3½ years post-abatement. Only minimal and routine maintenance work was needed, which most often consisted of resealing wood floors originally treated with polyurethane. Soil lead concentration, which ranged from 209 to 1,962 µg/g (geometric mean = 688 µg/g), was not a significant covariate in the statistical model, suggesting that soil was not a major contributor to the reaccumulation rate of lead in dust.

Major strengths: This is the first study to evaluate dust lead levels at least one year after a dwelling has undergone comprehensive abatement of lead paint hazards.

Major limitations: Although the authors state that they plan to periodically reevaluate the dwellings during non-winter months, the authors did not control for seasonal differences in dust lead levels. The pre-abatement dust lead levels may have been obtained during the summer months when occupants' use of windows and foot traffic patterns may differ from wintertime patterns. However, the effect of seasonal variation on the results is likely to be much less than the decreases in dust lead loading levels observed before and after interventions.

Conclusions: This study demonstrates a dramatic decline in dust lead loading which was sustained during the 1½ to 3½ years of normal use after the intervention was conducted. The authors note that comprehensive lead paint abatement is associated with the longer-term control of residential dust lead hazards, despite 1) the presence of lead in soil at levels of concern (>500-1,000 µg/g), 2) some reaccumulation of lead in dust, and 3) the locations of the dwellings in older housing areas where nearly all neighboring housing contains lead paint hazards. The findings suggest that occupants can maintain low dust lead levels with ordinary housecleaning methods once smooth surfaces are provided in the context of a comprehensive form of abatement.

Table 4. Geometric mean dust-lead levels (µg/ft²)* over time in dwellings that underwent experimental abatement, by type of surface, Baltimore, 1988-91 (Farfel, 1994a).

Surface type:	Pre-abatement dust lead level (µg/ft²)	Post-abatement dust lead level (µg/ft²) after clean-up	Post-abatement dust lead level (µg/ft²) 1.5 - 3.5 years
Floors			
Geometric mean	254	14	41
95% confidence interval	[143, 452]	[7, 25]	[25, 69]
Range	(16 - 12,641)	(3 - 159)	(3 - 2,807)
Number	42	47	71
Windowsills			
Geometric mean	1,042	13	103
95% confidence interval	[542, 2,008]	[7, 22]	[66, 161]
Range	(4 - 35,042)	(2 - 151)	(10 - 2,054)
Number	53	54	59
Window troughs			
Geometric mean	14,221	34	600
95% confidence interval	[7,343, 27,792]	[22, 49]	[345, 1,041]
Range	(266 - 301,623)	(8 - 233)	(11 - 15,058)
Number	31	41	49

* To convert to mg/m², divide the value for µg/ft² by 92.95.

Adapted from Table 1 on page 219 (Dust lead loadings (PbD, mg Pb/m²) over time by surface type): **Farfel, 1994a**. Farfel M.R., Chisolm J.J., Rhode C.A. *The long-term effectiveness of residential lead paint abatement.* Environmental Research 1994; 66:217-221.

Table 5. Model estimates of the ratios of 1.5- to 3.5-year follow-up dust lead loadings to those pre- and immediate post abatement.

Ratio:	Dust lead loading ratio (95 percent confidence interval): 1.5 to 3.5 years / Immediate post-abatement	Dust lead loading ratio (95 percent confidence interval): 1.5 to 3.5 years / Pre-abatement
Floor	3.0 (1.5, 6.3)	0.17 (0.09, 0.31)
Windowsill	8.2 (4.4, 15)	0.10 (0.05, 0.20)
Window trough	17 (9.1, 31)	0.04 (0.02, 0.08)

Adapted from Table 2 on page 220 (Model estimates of the ratios of 1.5- to 3.5-year follow-up dust lead loadings (PbD) to those pre- and immediate post-abatement): **Farfel, 1994a**. Farfel M.R., Chisolm J.J., Rhode C.A. *The long-term effectiveness of residential lead paint abatement.* Environmental Research 1994; 66:217-221.

5.3.4 HUD demonstration projects in public housing in Omaha (HUD, 1993) and Cambridge (HUD, 1994).

Objectives: To determine the comparative costs and benefits of various abatement strategies in public housing; to determine the most timely, efficient and effective strategies for incorporating lead paint abatement into comprehensive modernization programs; and to determine the degree of leaded dust migration during abatement. The data evaluates costs and feasibility, worker protection, containment, and clean-up.

Setting: Urban public housing developments built in 1938 (Omaha), 1938 (Newtowne Court -Cambridge), and 1955 (Putnam Gardens - Cambridge).

Outcome measurement: lead levels in dust, air, soil, and workers' blood.

Intervention (1991 to 1992): Building components were abated if the lead content of the paint was found to be $\geq$0.6 mg/cm² by XRF. This standard is stricter than the HUD standard (HUD, 1990) of 1.0 mg/cm². In Omaha, 34 percent of the XRF results were $\geq$1.0 mg/cm², but the proportion of results $\geq$1.0 mg/cm² varied greatly by building component: baseboards (99%), shelfcleats (97%), windowsills (86%), door frames (78%), ceilings (2%) and walls (1%). Similarly, in Cambridge, 16 percent of the XRF results were $\geq$1.0 mg/cm² but the proportion of results $\geq$1.0 mg/cm² varied greatly by building component. Neither report includes the distribution of higher XRF readings which would help quantify the extent of the lead hazards.

The lead abatement activities were conducted in accordance with the HUD interim guidelines (HUD, 1990) and were incorporated into modernization work underway at the housing developments. In Omaha, all interior and exterior components containing leaded paint were abated: the contractors enclosed ceilings and walls with sheetrock; and replaced doors, doorframes, windowsills, shelves, baseboards and other painted components. In Cambridge, the contractors encapsulated ceilings and walls; stripped door jambs and staircases; enclosed window surrounds and lintels; and removed doors, shelves, baseboards and chair-rails.

Methods:

a. Design issues:

study design: descriptive

method used to select dwellings : it contained leaded paint

use of a control group: no, but multiple interventions were compared

duration of follow-up: immediately post-abatement

completion of follow-up: 100%

b. General methods: Throughout the abatement phase of the demonstration project, data were collected to estimate costs and to evaluate the ability to carry out the assigned method of abatement. Data were also collected on airborne lead concentrations, immediately post-abatement surface dust lead levels, pre- and post-abatement soil lead concentrations, and workers' blood lead levels.

c. Dust sampling strategy and method(s) : Immediate post-abatement (clearance) dust wipe samples were collected after lead-contaminated building components were removed and the units were cleaned and before the remainder of modernization work started. The wipe samples were collected in accordance with the HUD Interim Guidelines (HUD, 1990).

Results:

<u>(Omaha report)</u> Concerning clean-up, 16 (32%) of the 49 units initially failed to meet the HUD dust lead

clearance standard at one or more of the sites tested. However, after the units were cleaned one more time, they all met the clearance standards. Exterior concrete surfaces were difficult to clean and achieve dust wipe results below the interior floor clearance standard of 200 µg/ft². Initially, only 4.5 percent of the 22 wipe tests on exterior concrete surfaces met the clearance standard. After repeated cleaning, using frequent changes of water and tri-sodium phosphate and rescrubbing with a sponge, 70 percent of the wipe tests met the clearance standard. Concerning containment, the mean soil lead level around one group of buildings increased from 109 µg/g before abatement to 157 µg/g after abatement. However, the air and dust wipe data showed no evidence of dust migration into adjacent units during abatement. Concerning worker protection, there was no evidence that airborne dust lead levels were hazardous while the work of removing painted building components was underway. Among 46 time-weighted average (TWA) personal air samples tested, only one exceeded 30 µg/m^3. None of the air samples exceeded 50 µg/m^3, which is the current Occupational Safety and Health Administration's (OSHA's) Permissible Exposure Limit (PEL) for an 8-hour work day. This finding, in combination with the use of respirators throughout this phase of the project, makes it unlikely that workers were adversely exposed to airborne lead levels. In fact, among seven workers tested after approximately two months on the job, the average blood lead level was 7.7 µg/dL (range: 3.6 - 12.8 µg/dL). No pre-employment blood lead levels were available.

<u>(Cambridge report)</u> Concerning clean-up, the contractors were fairly successful in meeting the HUD dust lead clearance standards during the first attempt. Over 95 percent of the window troughs and windowsills met wipe test clearance standards on the first attempt. Eighty-seven (87) percent of the initial wipe samples from floors met the clearance standard; however, the rate differed by the methods of lead removal used. The success rate of wipe tests on floors in the buildings that used chemical removal methods (80%) was lower than the rate for buildings that used mechanical methods (90%). Concerning containment, the pre- and post-abatement average soil lead level around the buildings did not significantly change, and air lead levels measured in adjacent units during abatement activities showed low levels of lead. Dust wipe data, however, showed evidence of possible dust migration into adjacent units during abatement. The report states that dust lead levels increased by 62 µg/ft² between pre- and post-abatement. However, since the pre-abatement levels are not reported it is difficult to interpret the importance of this increase. Concerning worker protection, there was evidence that airborne dust lead levels could be hazardous to unprotected workers during two activities. While 110 of the 117 eight-hour time-weighted average (TWA) air lead levels were less than 30 µg/m^3, three of the readings above 30 µg/m^3 occurred during final clean-up activities, and three readings above 200 µg/m^3 occurred when workers used needleguns to strip paint. Among 36 deleading workers that were tested pre- and post-abatement, the blood lead levels are reported to have remained below 25 µg/dL, and the largest observed increase in one worker was from 12 µg/dL to 18 µg/dL.

Major strengths: This project documents the implementation of the 1990 HUD interim guidelines in over 200 public housing units. The authors provide extensive cost data and share the strengths and deficiencies of abatement procedures so future abatement project planners can learn from their experience.

Major limitations: Dust lead measurements were not obtained before the demonstration project, nor were they measured several months after the intervention was completed.

Conclusions: The HUD demonstration project (HUD, 1993, 1994b) does not provide information to evaluate the short- or long-term effect of the intervention on lead hazards. However, the project provides information to evaluate costs, worker protection, containment, and clean-up; and shows that it is technically feasible to undertake comprehensive abatement of all lead-based paint in a dwelling. The reports indicate that when abatement activities are conducted in accordance with the HUD interim guidelines (HUD, 1990), workers and adjacent areas are generally not adversely exposed to lead. In addition, dust lead levels following single, and sometimes multiple, clean-up activities can be brought down below the HUD clearance standards. We do not know, however, what the dust lead levels were prior to the abatement work.

5.3.5 Murphy Homes (Georgia) abatement project (Jacobs, 1992)

Objectives: To assess the impact of abatement activities, completed in accordance with the HUD requirements contained in *Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing* (HUD, 1990), on abatement workers and the environment. The study evaluates the effectiveness of worker protection, containment, and clean-up. Costs were evaluated in very general terms.

Setting: Public housing development built in 1963 known to contain lead based paint on exterior and some interior surfaces.

Outcome measurement: lead levels in dust, air, soil and workers' blood.

Intervention (between October 1990 and March 1992): The intervention targeted exterior surfaces covered with lead-based paint above 1 mg/cm². Porch columns and trim, window sashes, soffits, and fascia boards were removed. Window frames were enclosed with a new window panning system because they could not be easily removed from the brick masonry. Window lintels, door jambs, and railings were treated with a pneumatic shrouded needle gun equipped with a HEPA vacuum local exhaust system. The procedures were conducted in accordance with the HUD interim guidelines (HUD, 1990). In addition, the top layer of exterior soil was vacuumed using a HEPA vacuum cleaner in some cases where post-abatement soil samples were greater than 500 µg/g or where paint chips were seen.

Methods:

a. Design issues:

study design: descriptive

method used to select dwellings : contained exterior leaded paint >1 mg/cm²

use of a control group : no

duration of follow-up : immediate post-abatement

completion of follow-up : 100%

b. General methods: Murphy homes is a conventional public housing development that underwent comprehensive modernization during this abatement project. A baseline risk assessment of seven units was conducted to characterize lead contamination of soil and interior dust. Before and after abatement, composite soil samples were collected near the foundation of each unit and in bare play areas, and were analyzed for lead by EPA method SW846. During the abatement work, air sampling was performed inside abatement workers' breathing zones using a battery-powered air sampling pump operating at a nominal flow rate of 2 liters per minute. Both total dust and airborne lead concentration time-weighted averages were determined, typically for full work shifts, for each worker. Samples were analyzed by NIOSH method 7082. Immediately after abatement and before additional rehabilitation work was initiated, each unit was cleaned, a visual inspection was conducted, and dust lead measurements were obtained. If the dust lead level exceeded the clearance standard, then the unit was recleaned and resampled.

c. Dust sampling strategy and method(s): Dust wipe samples were collected in accordance with the

HUD Interim Guidelines (HUD, 1990). "Little Ones Baby Wash Cloths" were used inside one-square foot templates or a premeasured area. Samples were analyzed by EPA method SW846-3050.

Pre-abatement dust samples were collected from the interiors of seven units. Usually three to four floor samples (living room, kitchen, and bedrooms), and one or two window trough and sill samples were collected inside each of the seven units. Immediate post-abatement dust wipe samples (clearance samples) were collected in all 208 units. Since primarily exterior abatement work was conducted, clearance wipe samples were collected mostly on porches and stoops; sampling of the interior surfaces was limited to one to three samples from floors or windows.

Results: Regarding the effectiveness of worker protection and containment, the results were favorable. Airborne lead levels in the workers' personal breathing zones were well below the OSHA action levels of 30 $\mu g/m^3$, and the employee's blood lead levels did not rise significantly from before to after the abatement work. In addition, lead loading levels on interior surfaces both before and after the work were below the applicable HUD clearance standards. Table 6 shows the dust lead loading and soil lead results presented in the report. The dust lead levels in window troughs decreased dramatically, probably due to the combination of enclosing the window trough and cleaning with a HEPA vacuum.

Table 6. Geometric mean dust lead loading and soil lead concentration before and immediately after abatement, Murphy Homes, Georgia (Jacobs, 1992).

Surface Type	When samples were collected in relation to the intervention	number of samples	geometric mean dust lead loading	95% confidence interval
Floors	before	26	26 µg/ft²	(22, 30)
	after	287	32 µg/ft²	(26, 38)
Window sills	before	9	41 µg/ft²	(32, 50)
	after	105	26 µg/ft²	(19, 33)
Window troughs	before	14	326 µg/ft²	(319, 333)
	after	38	46 µg/ft²	(40, 52)
Soil	before	17	69 µg/g	(66, 72)
	after	87	87 µg/g	(82, 92)

Some units required more than one round of cleaning before meeting clearance standards. Of the 208 units sampled for lead dust levels following abatement, 31 (15%) required a second cleanup, and six (3%) required a third cleanup. Porch floors, made of old porous concrete, were the surface that most commonly failed to meet the clearance standard. The contractor reported that the most common reason for repeated cleaning was that a new worker had been put on the job, and on-the-job training usually rectified the problem.

Major strengths: This project documents the implementation of the 1990 HUD interim guidelines in over 200 public housing units. The authors share the strengths and deficiencies in the abatement procedures so that future abatement project planners can learn from their experience.

Major limitations: This study does not assess the short- or long-term efficacy of the abatements after normal household use.

Conclusions: The demonstration project (Jacobs, 1992) does not provide information to evaluate the short- or long-term effect of the intervention on lead hazards. However, the project provides information to evaluate worker protection, containment, and clean-up; and shows that it is technically feasible to undertake comprehensive abatement of exterior lead-based paint in a public housing development. The report indicates that when abatement activities are conducted in accordance with the HUD interim guidelines (HUD, 1990), workers and adjacent areas are generally not adversely exposed to lead. In addition, repeated cleaning is sometimes required to achieve dust lead levels below the HUD clearance standards.

5.3.6 HUD/FHA Private Housing demonstration project (HUD, 1991b) and the Comprehensive Abatement Performance (CAP) study (EPA, 1992)

> **Note:** The final report for the CAP study has not yet been released by EPA. The unpublished manuscript that we reviewed (EPA, 1992) provides limited information.

Objectives: The demonstration project was conducted to assess the costs and feasibility of various abatement procedures and the effectiveness of worker protection, containment, clean-up, and long-term hazard reduction. The Comprehensive Abatement Performance (CAP) study was conducted to evaluate the long-term effectiveness of the methods used in the demonstration project.

Setting: The study evaluated 172 single-family dwellings from the inventory of FHA repossessed houses in seven metropolitan areas: Baltimore, Birmingham, Denver, Indianapolis, Seattle, Tacoma, and Washington. The age and condition of the dwellings are not described. However, the dwellings contained leaded paint.

Outcome measurement: lead levels in dust, air, soil, and workers' blood.

Intervention (1989 and 1990): Dwellings were selected for abatement if the lead content of paint was ≥ 1.0 mg/cm² by XRF, or was found to be "positive" using AAS when retested because the XRF reading was between 0.2 to 1.8 mg/cm².

The procedures were conducted in accordance with methods specified in the National Institute of Building Sciences, *Lead-Based Paint Testing, Abatement, Cleaning and Disposal Guidelines*, Washington, DC, March 1989 (NIBS, 1989). Five different methods of lead hazard control were evaluated: encapsulation, enclosure, and three removal methods (including on-site chemical stripping, on-site heat-gun stripping, and complete removal or replacement of painted components). A fourth removal method, on-site abrasive stripping, was found early on to be infeasible upon visual inspection; therefore, it was not used in the demonstration project.

Methods:

a. Design issues:

study design: descriptive, prospective

method used to select dwellings: they contained leaded paint

use of a control group: in the demonstration project, multiple interventions were compared. In the CAP study, houses without leaded surfaces were used to estimate background levels of lead in dust and soil.

duration of follow-up: immediately post-abatement for the HUD study and approximately two years for the EPA CAP study.

completion of follow-up: among the 169 dwellings in the demonstration project, 57 (34%) were evaluated for long-term efficacy.

b. General methods: After exhaustive testing of 304 candidate units for lead-based paint, 172 HUD-owned, vacant, single family units were selected for the demonstration project. These units were stratified by location (seven cities across the U.S.) and by the extent of lead hazards and were then randomly assigned to Unit Abatement Strategies. Throughout the abatement phase of the demonstration, data were collected to estimate costs and to evaluate the ability to carry out the assigned method of abatement. Data were also collected on airborne lead concentrations, immediately post-abatement surface dust lead levels, pre- and post-abatement soil lead concentrations, and workers' blood lead levels.

For the CAP study, since no single abatement method could be used uniformly throughout a given dwelling, the intervention for each dwelling was classified as either encapsulation/ enclosure (E/E) or removal, depending on which methods were used to abate the greatest surface area within a given dwelling. Twenty control dwellings were selected in Denver from among 40 dwellings that were not abated because they contained few components covered with lead-based paint.

c. Dust sampling strategy and method(s): For the HUD demonstration project, dust wipe samples were not collected prior to abatement. However, wipe samples were collected immediately post-abatement using the methods described in the HUD Interim guidelines (HUD, 1990). For the CAP study, follow-up dust samples were obtained using a vacuum sampling method which is not described in the CAP manuscript. However, from unpublished sources, the method was the "CAPS cyclone." The CAPS cyclone is a portable, AC-powered particle separation chamber sampler (similar to a cyclone) made from standard PVC pipe and pipe fittings and a commercially available handheld vacuum. The sampler was developed specifically for the CAP study and characterized in the laboratory by the Midwest Research Institute (MRI, 1992). Since wipe sampling was used for the HUD Demonstration project, a number of side-by-side wipe and vacuum samples were collected to compare the results from the two methods.

For the CAP study, the planned sampling locations in each household was: two perimeter floor area; two windowsills; two window troughs; two air ducts; two interior entryway floors; and two exterior entryway floors. Specific rooms and the actual number of samples collected were not reported in the CAP report.

Results: Regarding feasibility of the various methods, the method of on-site abrasive stripping was found upon visual inspection to be infeasible. Regarding worker protection, detailed information is available on ambient air and personal air lead levels, and the ineffectiveness of negative air pressure zones for reducing air lead levels. Airborne lead concentrations were found to be strongly influenced by the Unit Abatement Strategy and by the method of abatement being used. Air samples in units assigned to the hand-scrapping with heat gun strategy were most likely to exhibit high levels of airborne lead (almost 16 percent of all air samples exceeding 30 µg/m^3) while the Encapsulation and Replacement unit abatement strategies generated the least airborne lead (only about 4 percent of the air samples exceeding 30 µg/m^3). These findings were confirmed by examining the relationship between the abatement method in use and the level of airborne lead. Likewise, clearance testing that followed encapsulation, enclosure and building component replacement hazard control methods had the lowest failure rates, while chemical stripping and hand-scraping with a heat gun had the highest failure rates. Twenty-six percent of the dwellings failed the initial clearance dust lead tests and needed to be recleaned and resampled. Eventually, all the dwellings met the HUD clearance standard which demonstrates that clean-up can be achieved using the methods evaluated. Regarding containment, the soil lead data shows a statistically significant increase in the mean level from 755 µg/g to 867 µg/g after abatement. However, since the data is skewed, the change may not have remained significant if the data had been log transformed. Also, the soil results were not stratified by the method of abatement which may, in fact, be an important effect modifier.

The results of the CAP study will not be described because of the limitations of the brief summary report that we reviewed (EPA, 1992).

Major strengths: The demonstration project met most of its objectives and documents the implementation of the 1990 HUD interim guidelines in over 150 single-family dwellings.

Major limitations: Since dust lead measurements were not obtained prior to the demonstration project, the investigators cannot compare pre-intervention dust lead levels with follow-up levels obtained two years later for the CAP study. Furthermore, results from the dust sampling vacuum method used for the CAP study may not be directly comparable to either the initial wipe samples or to the HUD clearance standards. Finally, the comparison between the encapsulation/enclosure (E/E) methods and the removal methods may not be definitive because the pre-abatement dust lead levels in the two groups of houses may not be similar. The authors state that the dwellings that underwent E/E procedures were those dwellings that contained more leaded paint and underwent "significantly more abatement." Therefore, higher post-abatement dust lead levels in the dwellings that underwent E/E procedures may be due to the initial hazards rather than due to differences in the procedures.

Conclusions: The demonstration project report (HUD, 1991b) provides information to evaluate costs, feasibility, worker protection, containment, and clean-up. Among the five unit abatement strategies evaluated, the strategy that uses hand-scraping with a heat gun as the method of first choice was found to generate the highest air lead levels and to most frequently fail the initial dust wipe test. The report that describes the CAP study (EPA, 1992) provides little information to evaluate the long-term efficacy of the interventions used in the demonstration project. The final CAP study report, when released by the EPA, may provide more information.

5.4 Secondary prevention intervention studies

5.4.1 Baltimore dust control study (Charney, 1983)

Objectives: To assess whether the control of house dust would reduce the blood lead levels of children with blood lead levels between 30 and 49 µg/dL. The study addresses the short-term effect of dust control on lead hazards.

Setting: The children lived within the City of Baltimore in dwellings that had previously been inspected and treated for lead paint hazards.

Outcome measurement: blood and dust lead levels.

Intervention (1981 and 1982): The dwellings in this study had previously undergone the standard environmental intervention which involved removing all peeling or deteriorated leaded paint on interior and exterior surfaces within the dwelling. Intact surfaces with leaded paint below a 1.2 meter level were to be covered or rendered lead free if they presented an accessible surface from which paint might be chewed (windowsills, stairs, porches, and the like). The study evaluated additional dust control measures. These measures involved a "dust control team" of two research assistants who visited each experimental home twice monthly. All rooms (including windowsills) in the home that contained >100 µg of lead per sample were wet-mopped using a high-phosphate solution that was frequently changed during cleaning. The child's caretaker was advised to wash or wet-mop these identified "hot spots" more frequently (two or three times per week) in the interval between visits, to wash the child's hands before meals and at bedtime, and in some cases to limit access to high-lead areas.

Methods:

a. **Design issues:**

study design: prospective, experimental

use of a control group: yes

method used to select dwellings: it housed a lead-poisoned child and had already been inspected and treated for peeling paint

duration of follow-up: The children were followed for the 12-month period during which the ongoing intervention was implemented

completion of follow-up: 49 of 71 (69%) eligible children.

b. **General methods:** Children were selected for study from a Lead Poisoning Clinic (Baltimore) if they were between 15 and 72 months of age, and had at least two confirmed venous blood lead levels between 30 and 49 µg/dL and free erythrocyte protoporphyrin values below 655 µg/dL at the time of enrollment (subjects could have undergone prior chelation therapy one time and could have had higher blood lead levels earlier), and if they had lived at their present address for at least six months. The subjects were systematically assigned to one of the two study groups. Home visits were conducted to ensure that children in the dust control intervention group spend at least 80 percent of the time in a single dwelling.

c. **Dust sampling strategy and method(s):** Dust wipe samples were collected using a wipe sampling method which is similar, except for the laboratory digestion procedure, to the HUD wipe method. Samples were obtained from one-square foot areas, or from entire interior windowsills, in areas in the home where the child was said to spend time (usually the kitchen, the child's and parents' bedrooms, and one or more living areas). Areas found to be greater than 100 µg/sample (100 µg/ft^2 or 100 µg/windowsill) were designated as hot-spots and "dust-control teams" visited the homes twice monthly to wet-mop these areas. The child's caretaker was also asked to wet-mop these areas on a regular basis. Additional dust samples were collected by the dust-control teams in the designated areas before and after each cleaning to confirm that lead loading levels had been markedly reduced.

Results: Among children living in dwellings that underwent dust hazard control, the mean blood lead level decreased significantly from baseline ($p < 0.01$) after six and 12 months of the intervention (Table 7). However, the average blood lead level remained above 30 µg/dL. The children in the dust control intervention group with the highest initial blood lead values had the most marked reduction over the one-year study period ($r = -0.84$, $p < 0.001$). Interestingly, among the children living in dwellings that had previously undergone paint lead hazard control alone, the average blood lead level did not change over time.

Table 7. Mean blood lead levels among children participating in the dust control study, Baltimore, 1981-82 (Charney, 1983)

Intervention group (study population)	Mean blood lead level (µg/dL)			
	6 months before start	at start	6 months after start	12 months after start
Comparison population (n=35)	37.5	38.5 ± 5.2	38.7 ± 7.6*	37.8 ± 7.9

Dust hazard control population (n=14)	37.6	38.6 ± 5.2	33.3 ± 3.6	31.7 ± 2.6

* n=33

The dust lead data indicates that interior window sills, and floor areas adjacent to those windows, were the sites with the highest dust-lead loading values. It took several weeks to several months before all homes had a reduction in lead-containing dust that persisted between visits. After 12 months of the dust control intervention, none of the dwellings had lead loading levels $\geq$800 µg/ft² on the floors or $\geq$800 µg/window sill (initially, 57 percent of the dwellings had at least one site with lead loading levels this high). Among children living in dwellings that underwent dust hazard control, there was no significant relationship shown between the reduction in lead-contaminated dust in a given home (or the initial amount of lead-contaminated dust), and a reduction in a child's blood lead level. This lack of a dose response relationship is probably due to the variability of dust lead levels within a given house, and the multiple simultaneous strategies to reduce a child's exposure to lead.

Major strengths: A comparison population was used to evaluate the benefit of dust control efforts.

Major limitations: Although this study took place over a 12 month period, it does not measure the long-term efficacy of the dust control procedures. The study did not measure dust lead levels after the dust control teams stopped going to the dwelling every 2 weeks. Educating the family was the only sustainable experimental intervention provided.

Conclusions: Lead levels in house dust can be reduced by a regular and focused dust-control effort (every 2 weeks) over a 12-month period, and blood lead levels of children residing in those homes are significantly lower than the blood lead levels among children whose homes do not undergo dust hazard control.

The authors note that since a dose-response was not observed between the reduction in lead-contaminated dust and a child's blood lead level, it is not clear which aspect of the intervention is most responsible for the observed reduction in blood lead levels. It could be one or more of several alternatives: the home-cleaning done by the family or the "dust-control" team, the avoidance of highly contaminated areas in the home, or regular handwashing. However, the results indicate that lead hazard control activities should include the control of dust hazards in order to effectively reduce a child's exposure to lead.

Although this study measured the beneficial effect of a 12-month continuous dust-control intervention, the long-term efficacy of the intervention -- that is, after the dust control team visits were discontinued -- was not evaluated.

5.4.2 1990 St. Louis retrospective study (Staes, 1994)

Objectives: To evaluate the effectiveness of lead-based paint hazard control in reducing children's blood lead levels 4 to 14 months after diagnosis. The study evaluates the short- and long-term effect of the hazard control activities.

Setting: The children included in the study lived in a low-income, inner-city area of St. Louis in dwellings built between 1880 and 1931. Only seven percent of the dwellings were owner-occupied. All of the dwellings contained lead paint hazards, and most (85 percent) of the children were exposed to surfaces with XRF measurements of 2 mg/cm² or higher.

Outcome measurement: venous blood lead level.

Intervention (1989 and 1990): The procedures were limited and did not include many of the provisions in the interim HUD guidelines (HUD, 1990). At the time of the study, the dwelling owner in St. Louis was required to control lead hazards, defined as all interior- or exterior-painted surfaces that are chipping, peeling, or flaking that have a lead content of 0.7 mg/cm² or higher measured by XRF. Leaded paint on chewable surfaces, such as windowsills, was not required to be removed if it was intact. The procedures used were varied, not standardized, and were not directly supervised by the health department inspector. Families were not required to relocate from the dwelling during the remediation process, and it appeared that no children were relocated. The parents and dwelling owner were instructed to keep the child away from the work area and were given instructions about what procedures to use to control lead hazards. The procedures were considered complete when a health department inspector certified that all initially cited surfaces had been repaired (i.e., damaged paint removed and surfaces smoothed or replaced) and obvious remediation debris had been cleaned up. No dust lead measurements were used to identify hazards or to undertake clearance testing.

Methods:

a. **Design issues:**

   study design: Retrospective

   method used to select dwellings: it housed a lead-poisoned child

   use of a control group : yes

   duration of follow-up : 4 to 14 months after diagnosis

   completion of follow-up : Among the 185 children who met the selection criteria, 54 (29%) had blood lead measurements available at 10 to 14 months after diagnosis.

b. **General methods:** The authors reviewed existing St. Louis City Health Department records; identified 185 children younger than 6 years who had blood lead levels $\geq$25 µg/dL during 1989 or 1990; and compared changes in blood lead levels among children whose dwellings did and did not undergo remediation. Despite the requirement that owners must control lead hazards identified in inspected dwellings, some dwellings did not undergo lead hazard control during the study period because of delays for legal, financial, or other reasons. The authors also assessed the impact of incomplete follow-up on the estimated change in blood lead levels.

c. **Dust sampling strategy and method(s)** : dust sampling was not performed.

Results: Among 54 children who had not moved or received chelation therapy and had their blood lead levels measured 10 to 14 months after diagnosis, the geometric mean blood lead level decreased 23 percent among children living in remediated dwellings (n = 37) and 12 percent among children in non-remediated dwellings (n = 17) (p = 0.07, t test). The estimated size of the remediation effect was similar using multiple regression (-13%; 95% confidence interval (95% CI) -25 to 1; p = 0.06) and an approach based on generalized estimating equations (-16%, 95% CI -25% to -7%; p = 0.002), when adjusted for covariates. The effect of remediation was greater among children whose blood lead levels at diagnosis were $\geq$35 µg/dL (-22%) than among those whose blood lead levels at diagnosis were between 25 and 34 µg/dL (-1%).

Major strengths: The authors assumed that educational or other interventions initiated shortly after the diagnosis of lead poisoning could reduce blood lead levels among children even in the absence of lead hazard control. Therefore, they compared the change in blood lead levels at specified time intervals *after diagnosis* between groups of children living in remediated and non-remediated dwellings. Thus, both groups of children had the same opportunity to benefit from non-lead hazard control interventions, and the effect of the intervention could be estimated.

Major limitations: Since the study entailed a retrospective evaluation of existing data from a lead poisoning prevention program, dust lead measurements were unavailable and blood lead levels were measured at the discretion of the child's health care provider. The measured decrease in blood lead levels following the intervention is probably an underestimate because children with follow-up data at 10 to 14 months had less rapid early declines in blood lead levels than those without follow-up data. Therefore, the overall decline in blood lead levels may be larger than observed. However, the authors do not expect the loss to follow-up or exclusion criteria to bias the estimate of the effect of the intervention.

Conclusions: Among lead-poisoned children in St. Louis, children whose dwellings undergo lead paint hazard control show a greater decline in geometric mean blood lead level than children whose dwellings are not treated, but the effect of the intervention may be influenced by the blood lead level at diagnosis. Blood lead levels decrease to some extent without lead paint hazard control in the home environment. Therefore, other studies should not attribute all of the change in blood lead levels that follows lead hazard control solely to the lead hazard control intervention.

5.4.3 Boston retrospective study (Amitai, 1991)

Objectives: To evaluate the impact of "deleading" procedures on children's blood lead levels during and after the deleading process. This study addresses both containment and the long-term effect of the intervention.

Setting: The authors state that the children included in the study were enrolled in the Massachusetts Lead Poisoning Prevention Programs case management system; therefore, the children probably resided throughout the state of Massachusetts.

Outcome measurement: venous blood lead levels

Intervention: (1984 and 1985): The housing unit of each lead-poisoned child was examined by trained inspectors using XRF or sodium sulfide. Property owners were required to remove or permanently cover any paint with a lead content greater than 1.2 mg/cm^2 that was loose and peeling (at any height) or was present on chewable surfaces accessible to the child (below four feet). The inspector instructed parents and property owners on deleading procedures, the importance of removing children during the deleading process, and cleaning up by washing surfaces with tri-sodium phosphate detergent. These instructions were not uniformly followed and no mechanism was in place to provide alternative shelter for the families. Upon completion, the unit was inspected and, if no violations remained, repainted and declared safe.

Methods:

a. **Design issues:**

study design: retrospective

method used to select dwellings: it housed a lead-poisoned child

use of a control group: no

duration and completion of follow-up: Among the 114 children who met the selection criteria described in the general methods, all (by definition) had blood lead measurements obtained during the intervention. Fifty-nine (52%) had measurements obtained approximately 8 months (250 ±14 days) after the intervention.

b. **General methods:** The authors reviewed the *Massachusetts Lead Poisoning Prevention Programs* database and identified 114 children who met the following selection criteria: younger than 6 years who have a venous blood lead level >25 µg/dL prior to deleading; had at least one blood lead determination during and one after deleading; continual residence in the deleaded unit; and deleading of their dwelling had been completed in compliance with the state statutes.

c. **Dust sampling strategy and method(s):** dust sampling not performed.

Results: Among the 114 children in the study population, the mean blood lead level increased during deleading (mid-deleading) in comparison to the level prior to deleading (Table 8). The mean blood lead level reported at approximately 2 months after deleading includes the levels of 42 (37%) children who had been chelated. Among a subset of 59 children who had not moved or been chelated, the average blood lead level declined from 35.7 to 25.5 µg/dL.

Table 8. Blood lead results from the Boston Retrospective study (Amitai, 1991)

Timing of the blood lead measurement in relation to the intervention:	Mean blood lead level (µg/dL) pre-deleading immediately prior	mid-deleading* during	post-deleading about 2 months after	follow-up about 8 months after
Children in the study population (n=114):	36.4 ± 0.6	42.1 ± 1.5	33.5 ± 1.0 †	not calculated
Children with measurements available at follow-up and who had not moved or been chelated (n=59):	35.7 ± 0.9	35.5 ± 0.8	31 ± 1.0	25.5 ± 0.9

* If more than one measurement was available, then the results were averaged. Measurements obtained after chelation were excluded.

† Includes the blood lead levels of 42 (37%) children who had been chelated.

The authors report that dry scraping and sanding, used in 41 cases, was associated with an increase of 9.1 ± 2.4 µg/dL in "mid-deleading" blood lead levels compared to "pre-deleading" levels. By comparison, the blood lead levels of the 12 children whose homes underwent replacement and enclosure methods decreased by 2.2 ± 2.4 µg/dL. Among the four children's homes in which torches were used to soften paint prior to scraping, the "mid-deleading" blood lead levels were 98 percent higher (35.7 ± 10.8 µg/dL) than the "pre-deleading" levels.

Major strengths: The study describes the changes in blood lead levels observed among children exposed to various methods of lead paint reduction.

Major limitations: The authors *included* blood lead measurements that follow chelation in the calculation of the "post-deleading" mean blood lead level for the entire study population. Therefore, the decrease in blood lead levels between "post-deleading" and "mid-deleading" among the 114 children in the study population cannot be attributed solely to the lead hazard control activities. In addition, the decrease in mean blood lead levels observed at follow-up, about 8 months after the intervention, may be underestimated because blood lead measurements were obtained at the discretion of the child's health care provider. Children with poorer outcomes may be more likely to be followed longer. Since no control population was used, the decrease in blood lead levels between "follow-up" and "pre-deleading" among the 59 children not chelated cannot be attributed solely to the lead hazard control activities.

Conclusions: An increase in blood lead levels was observed among many children when torches were used to soften paint for scraping and when paint was sanded and dry scraped. Since no control population was studied for comparison, the long-term effects of the intervention are difficult to assess. The changes in blood lead levels reported after the completion of deleading can not be solely attributed to deleading of the child's home.

5.4.4 Worcester (MA) retrospective study (Swindell, 1994)

Objectives: To evaluate the effectiveness of lead-based paint hazard control in reducing children's blood lead levels up to one year after the environmental intervention. The study evaluates the short- and long-term effect of the hazard control activities.

Setting: Housing in the Worcester County area consists predominantly of two- and three-story wood frame dwellings, the great majority of which were built before 1950.

Outcome measurement: venous blood lead level.

Intervention (1987 and 1990): Policies governing lead hazard control activities changed during the study period. Prior to 1988, Massachusetts statutes required that (on surfaces with a lead content greater than 1.2 mg/cm^2) property owners remove or permanently cover all paint on chewable surfaces below 4 feet and make intact any loose or peeling paint on all other surfaces. There were no regulations regarding the lead hazard control process itself and there were no formal mandates regarding dust control, clean-up procedures and clearance. It was recommended, though not enforced, that children be removed from the home during the lead hazard control process and that clean-up procedures include washing with a tri-sodium phosphate solution. Since 1988, more stringent regulations have been enacted. For example, deleaders must be licensed; only hand-scraping and replacement of parts are acceptable removal methods; torching or machine-sanding are prohibited; and all occupants must be out of the dwelling during the entire deleading and cleaning process. Clean-up involves vacuuming all surfaces with a HEPA filter vacuum, followed by wet-mopping and sponging with a solution of tri-sodium phosphate and a second HEPA vacuuming.

Methods:

a. Design issues:

study design: Retrospective

method used to select dwellings: it housed a lead-poisoned child

use of a comparison group : no

duration of follow-up : up to one year after the intervention

completion of follow-up : Among the 195 children whose homes underwent lead paint hazard control during the study period, 132 (68 percent) qualified for enrollment.

b. General methods: The authors reviewed existing Massachusetts Department of Public Health case management system records of all children from central Massachusetts with a confirmed venous blood lead level $\geq$25 µg/dL from 1987 through 1990. Children were enrolled if they met specified eligibility criteria. Since study subjects had varying numbers of blood lead determinations, the venous blood lead value closest in time prior to the intervention was selected as the pre-intervention value for analysis and the last blood lead value (within one year) was selected as the post-intervention value.

c. Dust sampling strategy and method(s) : dust sampling was not performed.

Results: The study evaluated 132 children who had a mean pre-intervention blood lead level of 25.9 µg/dL. Their mean post-intervention blood lead (up to one year later) was 21.1 µg/dL, a statistically significant decrease (P <0.001). The reduction was similar among children whose homes were treated before and after the change in lead hazard control policies in 1988. The reduction in blood lead level within one year after the intervention varied markedly by the pre-intervention level. For example, 97 percent of the children with pre-intervention blood lead levels $\geq$30 µg/dL had decreased levels; 81 percent of the children with pre-intervention blood lead levels from 20 to 29 µg/dL had decreased levels at follow-up; and only 35 percent of the children with pre-intervention blood lead levels below 20 µg/dL had decreased levels at follow-up. The mean blood lead in the last group increased from 16.7 to 19.2 µg/dL (P = 0.05). The time of the last recorded blood lead level varied among the study subjects from 3 to 52 weeks after the intervention. Among the 24 subjects with elevated blood lead levels at follow-up, the elevated levels were distributed rather uniformly throughout the post-intervention year and not necessarily clustered around the time of the intervention.

Major strengths: The authors evaluated the change in the blood lead levels among children whose pre-intervention levels were as low as 15 to 20 µg/dL. As the blood lead level that triggers lead hazard control activities is lowered, it is important to study the appropriateness of these interventions for the secondary prevention of these lower levels of lead poisoning.

Major limitations: There was no control population of children whose homes did not undergo lead hazard control. Therefore, the decrease in blood lead levels cannot be attributed solely to this intervention. Since the study entailed a retrospective evaluation of existing case management data, blood lead levels were measured at the discretion of the child's health care provider which may result in an underestimate of the effect (Staes, 1994). In addition, dust lead measurements were unavailable. Finally, the authors did not provide information about the time that had elapsed between the intervention and follow-up, and did not control in the analysis for variations in this time-interval or seasonal differences.

Conclusions: The authors note that continued improvement in home abatement technology is needed if lead hazard control strategies are to be effective in achieving the lower blood lead levels now mandated in the 1991 Centers for Disease Control guidelines. Primary prevention of the initial blood lead level elevation remains the most desirable strategy. Since no control population was studied for comparison, the long-term effects of the intervention are difficult to assess. The changes in blood lead levels after the intervention cannot be solely attributed to deleading of the child's home.

5.4.5 New York chelation study (Rosen, 1993)

Note: An earlier study (Rosen, 1991) is not described because the methods and results are similar to Rosen 1993.

Objectives: to estimate lead in tibial cortical bones of lead-poisoned children by XRF following chelation treatment, compared with children who did not qualify for the 5 days of chelation therapy. The findings are potentially useful for assessing the long-term impact of the lead hazard control activities on the blood lead levels of those children not treated.

Setting: urban, older, deteriorated multiple-dwelling buildings located in New York City.

Outcome measurement: venous blood lead levels.

Intervention (1989 to 1991): The lead hazard control methods are not described in the manuscript; however, according to Andrew Goodman, M.D. (Assistant Commissioner of Community and Occupational Health) of the New York City Health Department, the following standard procedures were implemented at the time of this study. Dwellings that housed a lead-poisoned child were inspected, and peeling, chipping or deteriorated painted surfaces were tested with an XRF analyzer. Surfaces with XRF readings greater than 0.7 mg/cm^2 were required to be treated in one of the following ways: either enclose the surface with sheet rock, remove and replace the component, or remove the non-intact paint using any method except open-flame burners. The owner of the dwelling was given general instructions about conducting the work safely and cleaning up afterwards. However, anyone could do the work and the current HUD-proscribed procedures for containment, worker protection and clean-up were not required. Some dwellings required extensive lead hazard control work while other dwellings needed only minor work. Lead paint hazards were controlled in most apartments by the time of initial hospital discharge. For about 20 percent of the children, alternative housing was obtained until the housing repairs were complete. By 6 to 8 weeks post-enrollment, most of the major housing repairs had been completed.

Methods:

a. Design issues:

study design: prospective treatment outcome study

method used to select houses: it housed a lead-poisoned child

use of a control group: no

duration of follow-up: 6 months

completion of follow-up: over 90%.

b. General methods: The clinical research design was based upon a longitudinal assessment of 162 untreated lead-toxic children. At enrollment, blood lead values were determined. If the blood lead level was 25 to 55 µg/dL and the EP concentration in whole blood was $\geq$35 µg/dL, L-XRF measurements of tibial bone were carried out. One week later, each child underwent a $CaNa_2EDTA$ (chelation) provocative test. If the test was positive, the child was hospitalized and treated. These tests were repeated 6 weeks and 6 months after enrollment. During this 6-month period, if a child qualified for a second or third provocative test and additional $CaNa_2EDTA$ treatments, such regimens were carried out.

c. House dust sampling strategy and method(s): dust sampling was not performed

Results: Among the group of 87 children who were not eligible for chelation treatment because they had a negative result from chelation challenge, the mean blood lead level decreased from 27 to 21 µg/dL (a 22% decrease) at 6 months post-enrollment into the study.

Major strengths: Since the study was prospective and children were followed by the investigators, a high proportion of children were followed throughout the follow-up period.

Major limitations: Several factors may have influenced the observed change in blood lead levels. Most importantly, each child underwent a $CaNa_2EDTA$ provocative test one week and six months after enrollment into the study. Since there was no control group of children whose homes did not undergo lead hazard control, the observed blood lead level decrease cannot be solely attributed to the environmental interventions. Because this study was designed to evaluate a therapeutic intervention, the environmental interventions are not well described in the manuscript.

Conclusions: Since there was no control group and children received provocative chelation, the decrease in blood lead levels can not be solely attributed to the environmental intervention.

5.4.6 Boston -- EPA 3-city soil study (Weitzman, 1993; Aschengrau, 1994)

Objectives: To test the hypothesis that a reduction of 1,000 µg/g or more of lead in soil accessible to children would result in a decrease of at least 0.14 µmol/L (3 µg/dL) in blood lead levels.

Setting: Urban neighborhoods with a high incidence of childhood lead poisoning and high soil lead levels.

Outcome measurement: venous blood lead levels.

Phase I Intervention (1989-1990): The study group homes received loose interior paint removal, interior dust hazard control, and soil abatement. Comparison Group A houses received loose interior paint removal and interior dust hazard control. Comparison Group B houses received only loose interior paint removal.

Soil abatement consisted of removing a 15-cm layer of topsoil from the entire yard and replacing it with a water-permeable geotextile fabric covered by 20 cm of clean soil and then covered by either sod, grass seeding, bark, or mulch. Interior dust hazard control consisted of HEPA vacuuming and wiping surfaces with a wet cloth or an oil-treated rag for furniture. Floors, including carpeted areas, walls, woodwork, window troughs, and furniture surfaces were cleaned. Loose interior paint removal consisted of vacuuming loose paint areas with a HEPA vacuum, washing loose paint with a tri-sodium phosphate and water solution, and painting the window troughs with primer.

Phase II Intervention (1990-91): During Phase II, soil abatement was conducted in comparison groups A and B, and residential lead-based paint removal was offered to participants in all three groups.

Methods:

a. Design issues:

study design: randomized, controlled intervention trial

method used to select houses: located in one of several designated areas with a history of lead contaminated soil, and the dwelling housed a child with a blood lead level between 7 and 24 µg/dL, and the soil next to the dwelling contained at least 1,500 µg/g lead.

use of a control group: no, but had comparison groups

duration of follow-up: an average of 10 months (Phase I) and 9 months (Phase II) after the intervention.

completion of follow-up: Among 152 children enrolled for Phase I, 149 (98%) completed Phase I of the study. Among the 149 children eligible for Phase II of the study, 91 (61.1%) completed Phase II of the study.

b. **General methods:** Homes of potential participants were visited to determine if they met the following additional eligibility criteria: (1) chipping or peeling paint did not exceed 30% of the total surface area on the exterior walls of the child's home or exceed 40% on the walls of abutting premises; (2) premise had a yard of at least 0.9 m^2 composed of dirt and/or grass that was accessible to the child; (3) the mean or median surface soil lead level among samples taken near the house was at least 1,500 µg/g; (4) the child resided in a dwelling with eight or fewer residential units, was mobile, and according to parental report, had never been lead poisoned; and (5) the family resided on premises for at least 3 months and had no plans to move within the 3 months after enrollment.

Children were enrolled if they met these criteria and had a venous blood lead level between 7 and 24 µg/dL. Participants were randomly assigned to one of three groups: 54 in the study group, 51 in comparison group A, and 47 in comparison group B.

The researchers collected composite soil samples for XRF analyses, water samples, paint XRF measurements, dust samples, and social and behavioral information. Venous blood lead levels were measured prior to any hazard control activities, and an average of six and 11 months after baseline.

During Phase II, the authors: 1) described the change in blood lead levels among all study participants from before to after soil abatement; 2) evaluated characteristics influencing the effectiveness of soil abatement; and 3) assessed recontamination of soil and dust.

c. **Dust sampling strategy and method(s):** Dust on up-facing surfaces believed most accessible to the child was sampled by using a hand-held dust vacuum unit whose sampling head was modified to catch the dust sample in a fine mesh stainless steel screen (The Sirchee-Spittler dust sampling method). Six samples in each household were obtained from window troughs and floors from the kitchen, living room and the child's bedroom.

Results: Several weeks after soil abatement, the soil lead levels in the yards of study group homes decreased an average of 1790 µg/g (range: 160 to 5360 µg/g). An average of 33 weeks after implementing the interventions, the window trough dust lead levels declined 13 percent from baseline in the study group homes, 30 percent in comparison group A homes, and 26 percent in comparison group B homes. During this time period, the floor dust lead levels also declined and the proportion of homes with floor dust lead levels lower than baseline was highest for the study group homes (67 percent), next for comparison group A homes (54 percent), and lowest for comparison group B homes (42 percent).

The authors report that the mean decline in blood lead level between pre-abatement and 11 months after abatement was 2.44 µg/dL in the study group (P=.001), 0.91 µg/dL in group A (P=.04), and 0.52 µg/dL in group B (P=.31). When adjusted for pre-abatement lead level, the 11-month mean blood lead level was 1.28 µg/dL lower in the study group as compared with group A (P=.02) and 1.49 µg/dL lower than in group B (P=.01). The magnitude of the decline independently associated with soil abatement ranged from 0.8 to 1.6 µg/dL when the impact of potential confounders, such as water, dust, and paint lead levels, children's mouthing behaviors, and other characteristics, were controlled (Weitzman, 1993).

Following Phase II of the study, the authors report that lead-contaminated soil abatement was associated with a modest reduction in children's blood lead levels in both phases of the project. However, the reduction in Phase II was somewhat greater than that in Phase I. The combined results from both phases suggest that a soil lead reduction of 2060 µg/g is associated with a 2.25 to 2.70 µg/dL decline in blood lead levels. Low levels of soil recontamination 1 to 2 years following abatement indicate that the intervention is persistent, at least over the short-term. Furthermore, the intervention appears to benefit most children since no measurable differences in efficacy were observed for starting blood and soil lead level, race, neighborhood, gender, and many other characteristics. However, children who lived in apartments with consistently elevated floor dust lead loading levels derived almost no benefit from the soil abatement (Aschengrau, 1994).

Major strengths: This is a randomized, prospective study with high participation rates.

Major limitations: The study evaluated the impact of an intervention (soil removal) that is not a feasible option for most residences because of its high per unit cost. Furthermore, it is not known if results from the Sirchee-Spittler dust sampling method are comparable to the HUD wipe sampling method. Therefore, dust measurements made during this study cannot be directly compared to other studies.

Conclusions: The authors conclude that these results demonstrate that lead-contaminated soil contributes to the lead burden of urban children and that abatement of lead-contaminated soil around homes results in 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 (Weitzman, 1993).

5.5 Other studies reviewed

Other studies that focused on reducing residential lead exposures were reviewed but not included in the above reviews for various reasons. One study, which is unpublished, examined the effects of educational interventions to control lead based paint hazards (Schultz and Murphy, unpublished). Several other studies document lead hazard control efforts in communities polluted with lead by local smelters (Toronto, 1989 and 1990; Kimbrough, 1994; Trail, 1994). Another study assessed the potential to track lead into the dwelling and the effects of removing shoes or providing long walk-off mats at the door to reduce lead dust levels (Roberts, 1990 and 1991). While the primary lead sources in many of these studies were not necessarily housing-associated, all are briefly reviewed below because of their potential relevance to this report. Finally, a study that examined the feasibility of cleaning lead-contaminated carpets removed from houses with lead-poisoned children is also briefly reviewed (Ewers, 1994).

5.5.1 Milwaukee retrospective study (Schultz and Murphy, unpublished)

A retrospective study was conducted to evaluate the effectiveness of educational interventions implemented in Milwaukee during the years of 1990 through 1993. Children with lead levels between 20 and 24 µg/dL receive intensive educational services from outreach workers who are para-professionals employed by the City of Milwaukee Health Department. The educational services address nutrition, behavior change and housekeeping recommendations. The families of some children do not receive this intervention because they refuse the service or can not be located. The children whose families refused the service were used as controls.

The authors studied children who remained at the same address during the follow-up period, and who had blood lead levels (either venous and capillary) obtained by the health care provider during routine medical follow-up. The authors compared the mean blood lead levels of this group to the control group of children three to 12 months after their initial diagnosis. The distribution of the duration of follow-up was similar between the two groups. Among the 195 children who received the educational intervention, the average blood lead level decreased 4.0 µg/dL (an 18 percent decline). In comparison, among the 236 children who did <u>not</u> receive health department services, the average blood lead level decreased only 1.1 µg/dL (a 5 percent decline). The data is seasonally adjusted.

Despite limitations concerning the completeness and duration of follow-up, the selection of a control group, and the use of both venous and capillary blood lead testing and various laboratories for analysis, the data reflects the impact of normal service delivery as compared to highly-controlled services delivered as a part of a research study. The average blood lead level decreased in both groups; however, it decreased more among children whose families received in-home education, than among children who did not receive the education.

5.5.2 Granite City study (Kimbrough, 1994)

The objective of the Granite City study was to determine whether education and counseling of parents could reduce blood lead levels in their young children. The families live near a defunct lead smelter and were invited to participate in the study. After testing the blood lead levels of the children, all households with at least one child with an initial blood lead level of $\geq$10 µg/dL were visited, and the sources of lead in and around the home were discussed with the parents. The parents were given literature on the prevention of lead poisoning and on behavioral factors that increase the potential for lead exposure. They were instructed about handwashing and offering a well-balanced diet. Where indicated, suggestions were made to carefully remove peeling paint or to make sources of lead inaccessible in the home by installing barriers. Specific instructions on the safe removal of paint were provided, and the parents were also given advice on good housekeeping. The children with the elevated blood lead levels and their siblings were instructed not to put their hands and nonfood items into their mouths and to wash their hands before eating. Each session lasted 30 to 45 minutes.

The authors report a significant decrease in the children's blood lead levels over a twelve month period. Among a subset of 78 children with an initial blood lead level greater than 10 µg/dL, the mean blood lead level decreased from 15 µg/dL to 7.8 µg/dL in 51 of these children 4 months after the intervention. Since there is not a control group, and only children with blood lead levels *greater than* the initial mean blood lead level were retested, the observed reduction in mean blood lead may be due to regression to the mean, seasonal variation, and aging of the children, and can not be solely attributed to education and counseling of the parents. In addition, the authors do not specify whether the environmental interventions discussed during the counselling were actually implemented, nor whether the child resided in the same dwelling throughout follow-up. Therefore, it is not possible to determine whether the educational, environmental, or other interventions influenced the observed decline in blood lead levels, although the combination of these interventions probably contributed to the observed reductions.

5.5.3 Toronto study (Toronto, 1989; 1990)

This intervention project was conducted in an area with high airborne ambient lead levels from automobile traffic and a secondary lead smelter. This study was conducted by the City of Toronto Department of Public Health, in conjunction with the Ontario Ministry of the Environment. The lead reduction program focused only on household dust cleaning. Approximately 960 homes were intensively cleaned once from several major locations in the house: the duct work of the heating system; all floors; and unfinished walls and ceilings in the basement of the building (Toronto, 1990). No dust sampling was conducted in this study to determine effectiveness of the cleaning. However, eight homes were tested during the pilot phase (demonstration project) of the full study and dust samples were collected before and after cleaning (Toronto, 1989). While the primary sources of lead in the demonstration project were not housing-associated, the results are interesting and worth summarizing.

The Toronto demonstration project pre- and post-cleaning results from eight homes showed that 5 to 9 days after cleaning, the lead loading on floor surfaces (4 in each house) in selected high foot traffic areas were either significantly or marginally reduced in four of the eight dwellings and were either unchanged or marginally increased in the other four cases. A modification of the DVM vacuum sampling method [1] was used to sample the dust. The overall arithmetic average lead loading levels were 836 µg/ft² for pre-cleaning and 371 µg/ft² for post-cleaning. Surfaces that were heavily loaded prior to cleaning exhibited the largest reduction in lead loading, as would be expected. However, this reduction in the heavily loaded areas probably had a strong downward effect on the post-cleaning arithmetic average. Stated another way, the large difference observed between the before and after arithmetic averages may be due to just a few very high lead levels measured before cleaning. Lead concentration (µg/g) levels increased slightly after cleaning.

After 4 months, the surface sampling was repeated, but with an unspecified "high vacuum pump" sampler, in all eight houses. The samples collected indicated that the relative lead concentrations were similar to the pre-cleaning concentrations, except in one house where extensive renovations were being done. In this house, lead concentration increased by 900 µg/g. The overall lead loading arithmetic average was 465 µg/ft² 4 months after cleaning.

5.5.4 Seattle track-in study (Roberts, 1990; 1991)

In the Seattle track-in study, house dust and soil samples were collected in 42 homes built before 1950. Low-cost interventions, such as removing shoes at the front door, using long walk-off mats, and using vacuum cleaners with a beater bar were examined. House dust was collected with an upright Hoover Convertible vacuum cleaner from rugs using a modified ASTM Method F608-79. The method was designed to measure dust loading (g/m²) from rugs to characterize the efficiency and precision of commercial vacuum cleaners commonly available to the public. Both lead loading and concentration were determined for particles that passed through a 100 mesh sieve (less than 150 µm). The dust was analyzed by laboratory Energy Dispersive X-ray Fluorescence (XRF). Specific rooms and areas sampled were not discussed in the report. This report provides only limited information to assess the efficacy of controlling housing-associated lead hazards.

5.5.5 Trail lead study (Trail, 1994)

Trail, British Columbia has been the site of a major lead smelter for most of this century. As a result, the ambient air and soil lead levels are higher than surrounding areas, as are the children's blood lead levels. In 1990 the Trail Community Lead Task Force was formed to educate the residents and to develop strategies to lower community lead exposures. One of the task force's recent research projects studied the effect of repeated (every 6 weeks) HEPA vacuuming in homes for 10 months. An important finding of the Trail study was the limited efficacy of repeated cleaning in an environment heavily contaminated with lead. While the results of the study showed no statistically or clinically significantly decrease in children's blood lead levels as compared to a control group, the observed relationship between dust and blood lead levels was very interesting.

In the Trail study, HEPA vacuum bag lead loading measurements correlated better with children's blood lead levels ($r = 0.61$, $n = 55$) than lead loading measured with the DVM vacuum sampling method ($r = 0.50$, $n = 55$). The authors state that it is possible that the whole-house sample collected by HEPA vacuuming is more representative of a child's indoor exposure than are carpet dust samples from small areas in a few rooms.

5.5.6 Carpet cleaning study (Ewers, 1994)

This study assessed the feasibility of cleaning lead-contaminated carpets. Household carpets removed from homes of children in Ohio with high blood lead levels could not be cleaned effectively by repetitive vacuuming with HEPA-filtered cleaners. The lead concentration in the removed dust remained about the same from the initial cleaning to the tenth cleaning. The lead loading on the surface of the carpets was sometimes

[1] The DVM dust sampler is made from common industrial hygiene sampling materials and was developed by researchers at the University of Cincinnati.

increased during cleaning, possibly because vacuuming brought lead from deeper in the carpet up to the surface. Ewers and colleagues concluded that it may be more practical to replace heavily contaminated carpets rather than clean them.

6. Potential Sources of Information from Hazard Control Programs

Few residential lead hazard control programs are designed to assess the short- and long-term efficacy of reducing housing-associated lead hazards. For one thing, the resources for hazard control work are usually limited and the extra money needed to do an efficacy assessment is typically used for other purposes, such as identifying and treating additional dwellings with lead-based paint hazards. Furthermore, efficacy studies require the collection of numerous environmental and/or blood lead samples over time, developing and managing a data collection system, using monetary incentives or other techniques to retain participants in the study, and performing the complicated statistical analyses needed to draw meaningful conclusions from the data. Most hazard control programs in the United States do not have the personnel, time, or resources needed to conduct the extensive follow-up required to assess the efficacy of the lead hazard control activities. However, a few health departments and housing programs in the U.S. are either conducting their own research or collecting routine dust and blood lead information that could prove beneficial to researchers. Undoubtedly, there are other hazard control programs throughout the country with potentially useful data.

To identify potential sources of information, site visits or personal communications were made to several health departments and housing programs in the U.S. known to be actively involved in lead hazard control activities. The purpose of the contacts was to examine the type of data routinely collected and to assess its potential utility for conducting an efficacy analysis. This section reviews the findings from these contacts.

6.1 City of Milwaukee Health Department studies

The City of Milwaukee Health Department (MHD), in cooperation with the EPA and the University of Wisconsin, is actively conducting research designed to examine the impact of educational and/or environmental interventions on reducing lead levels in house dust and children's blood. The research focuses on children from primarily low income, urban families living in older homes in Milwaukee's central city. Both prospective and retrospective studies, with control groups, are currently being conducted in Milwaukee and some preliminary results are presented below.

It should be noted that all of the results reported from the following Milwaukee studies are preliminary. Final results and a more comprehensive discussion of the studies should be available soon from the researchers Schultz, Murphy, Kindrai, Biedrzycki, and others associated with these projects.

Study 1: In Milwaukee, children with baseline blood lead levels between 20 and 24 µg/dL receive an intensive educational intervention defined by a home visit conducted by a MHD outreach worker. With this information, the MHD conducted a prospective study designed to assess the effectiveness of in-home educational interventions on reducing children's blood lead levels and dust lead levels. Children 9 months to 6 years of age were selected for the study, if their primary dwelling unit had not received lead hazard control interventions since June 1992, a year prior to when the prospective study began. Following recruitment of families, a home visit was conducted by an outreach worker and by an environmental sampler. The outreach worker administered a questionnaire and provided intensive educational services while the environmental sampler collected soil, dust and water samples. These pre-intervention, or base-line, measurements are later compared with post-intervention measurements made from the same household. Additional blood and dust samples were collected during two return visits at 2 months and one year post intervention. The control subjects for this study were "self-selected". They are children who either received educational interventions before the study began or were unable to be contacted by the MHD outreach worker after three attempts. While data analysis for this prospective study is currently ongoing, preliminary results are available.

Preliminary results after two months of follow-up indicate that an average blood lead level decrease of approximately 4 µg/dL was observed in children who received educational intervention (cases, n=54) compared with a drop of 1 µg/dL in children who did not receive MHD services (controls, n=122). These results are seasonally adjusted.

Study 2: Another prospective study being conducted in Milwaukee examines children with blood lead levels between 25 and 44 µg/dL whose families receive nursing case management and environmental services from MHD staff. In order to assess the effectiveness of these interventions, MHD outreach workers conduct post-intervention blood lead tests 4 to 8 weeks after the completion of the environmental intervention.

The MHD inspector assesses lead paint hazards (primarily by XRF measurements) in dwellings and facilitates lead hazard control activities with property owners and certified lead abatement contractors via legally binding work orders. The work generally follows the practices outlined in the new HUD guidelines (HUD, 1994a) and addresses all deteriorated painted surfaces and dust removal. Undamaged surfaces are not treated. These practices also include maintaining the proper worker protection, containment, and clean-up provisions needed to safely conduct lead hazard control activities. Results from this study are pending.

Study 3: In addition to the retrospective education intervention study described in Section 5.5.1, the researchers in Milwaukee are retrospectively evaluating the effectiveness of lead hazard control strategies implemented in Milwaukee between 1989 and 1992. For children with blood lead levels $\geq$25 µg/dL, both educational and environmental services are delivered. Specifically, educational home visits are conducted by public health nurses and lead hazard control is facilitated by environmental inspectors. Lead hazard control work focuses on damaged painted surfaces that contain lead ($\geq$1.0 mg/cm² as measured by an XRF).

Preliminary results show that among the 104 children who received lead hazard control services and remained at the same address, the average blood lead level declined approximately 24 percent; and among the 236 children who did not receive these services, the average blood lead level declined approximately 5 percent. The results are seasonally adjusted. Further data collection and analysis will focus on the impact of the nursing case management/education interventions.

Study 4: Finally, the MHD is conducting a prospective dust wipe pilot project to collect information on dust lead levels in homes of lead poisoned children before and after lead hazard control interventions (Kindrai and Biedrzycki, unpublished). As noted above, the MHD conducts environmental inspections and orders lead hazard control activities in dwelling units that house lead poisoned children ($\geq$25 µg/dL). The lead hazard control work addresses all damaged lead-based paint surfaces but requires no action on undamaged surfaces. The treatments primarily include scraping and repainting of walls and windowsills, as well as enclosure of window troughs and floors.

The housing units are selected randomly for inclusion in the dust wipe pilot project -- one housing unit per inspector is randomly selected each week. Ten dust wipe samples are typically collected in each selected dwelling before and after the hazard control interventions. The samples are collected from the following surfaces: living room windowsill and well; kitchen windowsill and well; child's bedroom windowsill and well; living room floor; kitchen floor; bedroom floor and entryway floor. All windowsill and well samples are collected from the "most used" windows in each respective room. Only uncarpeted floors are sampled; and the entryway sampled is the most used entryway. One field blank sample per residence is also collected and analyzed. The post-intervention dust wipe samples are collected as close to the time that lead hazard control activities are completed as possible. However, to date, 30 percent of the samples were collected 30 days or more after the interventions.

Although sample collection and analysis is ongoing, approximately 500 pre-intervention dust wipe samples have been collected in 50 households. Post-intervention dust wipe samples have also been collected in a number of these homes. The following preliminary results are available from the housing units that have both pre- and post-intervention measurements (full statistical analysis has not yet been completed):

Geometric Mean Dust Wipe Results (μg/ft²):

	Pre-Intervention	Post-Intervention
Windowsills (n=53 pairs)	237	210
Window Troughs (n=41 pairs)	15,433	385
Floors (n=38 pairs)	50	81

A major strength of the Milwaukee dust wipe pilot study is that it measures dust lead levels during routine and normal field activities that reflect a mixture of lead hazard control treatments (i.e., it reflects the real world). Only state-certified lead abatement contractors or homeowners trained by the MHD are used, and containment implemented during the interventions is based roughly on the new HUD guidelines (HUD, 1994a). Another strength is that the study is conducted over the entire year so that seasonal trends in interior dust lead levels can be evaluated. A limitation of the study is that there is no control group with which to compare changes in dust lead levels.

6.2 "City Homes" (non-profit agency in Baltimore)

The objective of "City Homes" is to provide clean, safe, and affordable rental housing for low-income families in the Baltimore area and to make tenants aware of the services and programs available in their community. City Homes buys bulk packages of single-family Baltimore rowhouses from landlords for which purchase and rehabilitation costs are estimated at $18,000 to $28,000. Three predominantly low-income neighborhoods in Baltimore are targeted and are designated by City Homes as Projects I, II, and III. The number of homes currently owned are as follows: 37 in Project I, 34 in Project II, and 69 in Project III.

Environmental interventions to control lead hazards are conducted when units are vacant, either immediately after purchase or after a family moves out, and before a new tenant moves in. Thorough paint lead inspections are conducted with portable XRFs to identify surfaces with lead-based paint. Dust-lead wipe samples are also routinely collected.

Three levels of intervention are used to reduce lead-based paint hazards in City Home dwellings. These are basically the same interventions described in the current EPA-funded Repair and Maintenance (R&M) study described further in Section 7.2. Level I intervention includes wet scraping and limited repainting of deteriorated lead paint on interior surfaces; wet cleaning with high phosphate detergent and vacuuming with a HEPA vacuum; installing an entryway mat; educating occupants and owners; and stabilizing exterior surfaces to the extent possible. Level II includes all of the interventions in Level I, but adds floor treatments to make them smooth and cleanable, and in-place window and door treatments to reduce lead dust generated by friction. Level III interventions include window replacement; floor, doorway, and stairway treatments; and enclosure of selected wall and trim surfaces. The majority of the dwellings receive Level III interventions.

Dust lead loading measurements are made with the Maryland wipe sampling method (similar to HUD). Dust wipe samples are always collected for clearance purposes immediately post-intervention and before a unit is turned over to a new family, unless the unit is slated for lead hazard control work, since clearance samples will be collected when the work is completed. Six to eight dust wipe samples are usually collected from floors, windowsills, and window troughs. If dust lead loading levels exceed the Maryland clearance standards, the unit is re-cleaned and follow-up wipe samples are collected from the areas that failed clearance. For example, if six samples were collected for clearance purposes and two failed, then the area would be re-cleaned and two follow-up samples would be collected from the areas that failed. Although some pre-intervention dust data are available, this is not typically collected in units targeted for treatment. For example, dust was not sampled in most of the Project III units before interventions.

The City Homes project's strength is that it accomplishes its objectives: to provide clean, safe, and affordable rental housing for low-income families and to make tenants aware of the services and programs available in their community. It also uses state-of-the art abatement and interim control techniques, similar to those described in the new HUD guidelines (HUD, 1994a) to rent lead-safe houses to families with children. However, the routine data collected by City Homes is not suited for conducting an efficacy study.

A weakness in examining the data for efficacy is that 26 percent of the house files are not available for review because they are part of the EPA R&M study described in Section 7.2 (19% of the homes from Project I, 35% from Project II, and 25% from Project III). It is likely that the homes selected for the R&M study had the most extensive or complete records on environmental sampling. Extensive environmental sampling and follow-up is being conducted in the R&M houses as part of the EPA study, but this information is not yet available. Another weakness is that pre-intervention dust lead levels are not known for a many of the units. Finally, locating pertinent information for an efficacy study was tedious because of the extraneous contractual and other housing-related information contained in the files for each dwelling.

Environmental data is also missing from the files when the Maryland State Community Development Administration (CDA) is involved with a condemned house that City Homes purchases. The CDA sometimes funds its own interventions and dust sampling and City Homes does not duplicate those efforts. Sampling results from the state agency are typically not forwarded to City Homes. Thus, this information is not available from the house files.

Finally, City Homes provides routine blood lead screening for children 6 and under living in their homes, but children identified with elevated blood lead levels are referred to the Kennedy Krieger Institute in Baltimore for follow-up. Records of any follow-up testing or medical treatment are not forwarded to the house files.

6.3 Macon (GA) Housing Authority lead-based paint interim control project at five housing developments

Site description: This project concerns five housing developments that were all built in the early 1940's. Since there may be differences between the developments, each development should probably be evaluated separately.

Pre-intervention dust lead data: A risk assessment was conducted by the Housing Environmental Services, Inc. The dwelling units were selected using the targeted sampling approach contained in the new HUD guidelines, i.e. they were selected by determining which units had chronic maintenance problems, had the most children, and which units the housing authority felt had the worst housekeeping and other physical deficiencies. Dust samples were collected from floors in the kitchen, living room and the bedrooms.

Intervention: The intervention is an interim control strategy to remove lead contaminated dust, primarily by cleaning window troughs of debris and dust. Approximately 16 dwellings are treated in one day.

Post-intervention dust lead data: At the end of each day, one unit is randomly selected from the 16 units completed that day. Eight dust wipe samples are obtained from the one unit (1-2 floor, 7 window-well and windowsill) for clearance testing. If the lead levels are above the HUD clearance criteria, then all 16 units are recleaned and resampled. Between May and September, 1994, approximately 40 units were sampled.

Conclusion: The data could be useful for describing whether these in-place management procedures can be done in such a way that HUD clearance standards can be met. If the risk assessment results are generalizable, then it will be useful for evaluating whether or not the dust lead levels actually increased, despite remaining under the HUD clearance levels.

Recommendation: It would be useful to explore this data further to evaluate the change in dust lead levels in dwellings that were treated, using interim control procedures to control dust and debris, simply because leaded paint was present.

6.4 Cambridge (Massachusetts) Housing Authority (CHA) lead-based paint abatement project at Newtowne Court.

Site description: Newtowne Court consists of 282 units and was built between 1935 and 1938. Two 12-unit buildings were vacated, renovated and abated for the HUD Demonstration Project conducted 9/91-2/92. HUD is reporting its evaluation of these abatements (HUD, 1994b). The Cambridge Housing Authority (CHA) is planning comprehensive modernization of 6 buildings (258 units) in four phases: phase one started in August of 1993 and is currently underway; phase 2 is planned to start in November 1994, followed by phase 3 and 4. There are 74 to 86 units in each phase.

Pre-intervention dust lead data : pre-abatements were obtained in the two twelve unit buildings in the HUD demonstration project. During the following four phases, no pre-abatement dust samples were obtained within the units to be abated. XRF readings and chip analyses (AAS) are documented in reports.

Intervention: The abatement procedures, which are in compliance with the HUD guidelines, are documented in the specifications.

Dust lead data post-intervention : Clearance dust samples are being obtained from the units that were abated immediately following completion of the work. Re-occupancy wipes will be obtained after the additional modernization work has been completed and immediately prior to re-occupancy by the residents.

Conclusion: This project provides a site for evaluating abatements conducted in accordance with the HUD guidelines.

Recommendation: The data that is currently being collected is similar to the data that is already available from the demonstration projects described above. However, if dust lead levels were measured prior to abatement and after "normal" use of the dwellings by the occupants, then this site could be used to assess the long-term effectiveness of the interim HUD abatement guidelines for controlling hazards in public housing.

6.5 Cambridge (Massachusetts) Housing Authority (CHA) lead-based paint abatement project at Putnam Gardens.

Site description: Putnam Gardens consists of 123 units in 3 buildings and was built between 1948 and 1955. The level of lead hazards was present but low. The CHA has reports that describe the lead hazards (using XRF readings and paint chip analysis), the abatement method to be used, and the clearance dust lead results for each door. The specific location of these samples are documented. The letter of compliance describes the work that was done. Abatement work was conducted between November, 1990 and December, 1993.

Pre-intervention dust lead data: Using the risk assessment protocol, a few units (believed to be about 5% of the units) were randomly selected and 3 samples were obtained per unit. The data is in the CHA files.

Intervention: The abatement procedures are documented in the project specifications and in the memorandums describing the work that was done.

Dust lead data post-intervention : Dated clearance dust sample results are documented in the memorandum. These samples are taken immediately upon completion of the abatement work. Re-occupancy clearance results are also available at the CHA.

Conclusion: The CHA has post-abatement and re-occupancy data for each unit. They believe the data shows a re-occupancy failure rate of 15 to 25 percent, but they feel further analysis of this data is needed (Margaret Donnolly-Moran, personal communication). They believe the HUD Guidelines should include retesting units after extensive modernization work has followed abatement, and before re-occupancy.

Recommendation: A simple analysis of the pre-abatement, immediate post-abatement, and re-occupancy dust lead levels should be done to address the potential for reaccumulation of dust hazards following modernization of an already abated dwelling.

6.6 Lynchburg (Virginia) SWAB program (Lynchburg, 1994)

The Lynchburg Environmental Health Department initiated a behavior modification pilot project between September, 1993 and April, 1994 for 10 families with at least one lead-poisoned child. The primary goal of the project was to teach the participating families how to use housekeeping techniques designed to lower dust levels, and to incorporate the techniques into their routine cleaning. The program components were as follows: inspection of each home for lead-based paint by portable XRF and baseline soil and dust sampling; teaching of basic housekeeping techniques to remove clutter; and instruction in special techniques using tri-sodium phosphate (TSP) and HEPA vacuum. In four of the homes, trim work (primarily windows) was painted to cover badly peeling paint.

Weekly visits were made to the participating families to teach and observe cleaning techniques. Participants were instructed to wet wipe with a TSP spray bottle every other day and to log their activities. HEPA vacuums were usually used every 2 weeks. Dust samples and children's blood lead levels were measured approximately every 2 months for 8 months.

Numerous problems were encountered and documented during this project. Four of the ten families did not complete the study for various reasons. Sampling visits and follow-up over the holiday season (December to January) were limited or nonexistent. Adjustments to housekeeping (and limited lead removal) were made to meet each participant's needs. Some homes were owner-occupied, which may have caused more enthusiasm towards SWAB. Finally, families had different reactions to the program, and most families canceled appointments (some frequently).

Slight decreases in dust and/or blood lead levels were noted by the health department in most, but not all, of the families. Statistical analysis was not conducted in the report reviewed. The pilot project is most useful for documenting the feasibility and potential problems of implementing a behavior modification program in low-income households where lead-poisoned children reside. The Lynchburg Health Department has examined the strengths and weaknesses of the SWAB pilot program and developed a list of recommendations for future projects with similar objectives.

7. Summary of Current Studies

Some ongoing prospective studies are well designed to measure the impact of interventions over time. The major studies identified are listed below and described using the same framework as in Section 5. The results from most of these studies are more than a year away.

7.1 Evaluation of the HUD lead-based paint hazard control grant program in private housing (Lead-Safe Housing, 1994)

Objectives: To evaluate the cost, efficacy, and longevity of lead-based paint hazard control efforts conducted by 14 state and local government grantees under Rounds I and II of the HUD grant program (HUD Notice of Funding Availability, July 6, 1992 and 1993). The protocols, data collection instruments and all objectives are available from the National Center for Lead-Safe Housing.

Outcome measurement: dust lead loading measurements and blood lead levels; costs.

Intervention: Various environmental interventions determined by the grantees. HUD is encouraging state and local governments to experiment with new and innovative low-cost intervention strategies for this program.

Methods:

a. Design issues

study design: prospective

method used to select dwellings: determined by each grantee. However, in addition to the requirements imposed by HUD that the funds be used only in "target housing" (Title X, 1992), it is expected that grantees will select dwellings based in part on opportunities created by other programs, such as housing rehabilitation, or on a priority needs basis (the presence of a lead poisoned child in a household or identification of an imminent lead hazard in a dwelling occupied by a child).

use of a control group : no

duration of follow-up : 12 months after enrollment

completion of follow-up : pending

b. Dust sampling strategy and method(s) : The evaluation will collect dust samples for the first year following treatment in about 4,000 houses. Pre-treatment (baseline) dust lead loadings will be determined, and lead loading levels will be measured immediately following treatment for clearance purposes. Additional samples will be collected at 6 and 12 months post-treatment. Dust sampling will coincide with blood lead sampling in dwellings with children. Soil sampling is optional in this study.

The evaluation requires using the HUD wipe sampling method on all surfaces except carpets. Vacuum sampling with the University of Cincinnati dust vacuum method (DVM) is recommended on carpets, but is not required. It is anticipated that 30 to 38 dust samples will be collected per dwelling over the year. Typical sampling locations will consist of the floor inside the front door; the kitchen, principal play area, and bedroom(s) floors; and the principal play area and bedroom(s) windowsills and troughs.

Results and Conclusions: Pending

Major strengths: The study is prospective and examines how state and local programs actually perform outside a controlled research environment. Another strength is that the short- and long-term effects of numerous abatement and interim control practices can be evaluated, and many dust measurements will be collected in each home. Standard data collection protocols are being used by all grantees.

Major limitations: The evaluation may have limited statistical power to estimate and compare some outcomes of interest. This is primarily because types and numbers of dwellings treated using various strategies and methods cannot be controlled as part of the evaluation design. In addition, HUD encourages but does not require the grantees to treat only dwellings with children living in them. Although no control group was used, comparisons can be made between various interventions and before and after the intervention was completed.

7.2 The lead paint abatement and repair and maintenance (R&M) study in Baltimore (Farfel, 1994)

Objectives: To characterize and compare the short- and long-term efficacy of three levels of repair and maintenance and lead abatement interventions for reducing lead in settled house dust and in children's blood; to characterize the dust/blood lead relationship; and to investigate different dust collection methods.

Outcome measurement: Dust lead loading and concentration measurements, blood lead levels.

Intervention: Three levels of intervention are being used in the R&M dwellings. Treatment costs are as follows:

Level I	$1,650
Level II	$3,500
Level III	$6,000

Level I treatment consists of wet scraping of peeling and flaking leaded paint on interior surfaces, limited repainting of scraped surfaces, wet cleaning with high phosphate detergent and vacuuming with a HEPA vacuum to the extent possible in an occupied unit, installation of an entryway mat, education of occupants and owners, and stabilization of exterior surfaces to the extent possible given the budget cap. Two key elements added in Level II are floor treatments to make them smooth and cleanable and in-place window and door treatments to reduce leaded dust generated by friction. Level III adds window replacement; floor, doorway and stairway treatments; and enclosure of certain wall and trim surfaces.

Methods:

a. Design issues

study design: prospective, R&M dwellings randomized

method used to select dwellings: see description that follows

use of a control group : yes

duration of follow-up : 24 months after enrollment

completion of follow-up : pending

b. General Methods: Seventy five dwellings meeting the criteria described below were randomized into three equal groups (25 each), based on the following procedure: occupied dwellings randomly assigned to receive either R&M Level I or II interventions; dwellings vacant at the time of intervention randomly assigned to receive R&M Level II or III interventions. The intervention dwellings are typically two-story rowhouses with similar room layouts and many are owned by "City Homes" (see Section 6.2). Two control groups of 15 dwellings each are included in the study. One control group represents dwellings that received full lead-abatement performed by pilot abatement projects in Baltimore between May 1988 and February 1991. Pre-abatement and immediate post-abatement dust data is available for this group. The other control group is modern urban dwellings free of lead-based paint.

For the R&M groups, baseline venous blood lead levels were determined in children 6 months to 4 years. Pre-intervention dust, soil, and water samples were also collected. Follow-up blood and house dust samples are collected at immediate post-intervention (dust only), 2, 6, 12, 18, and 24 months after the intervention. Follow-up soil and water samples are scheduled for immediate post-abatement (soil only), 6, and 18 months post-intervention. For the control groups, blood and settled dust lead levels are measured at enrollment, 6, 12, 18, and 24 months after enrollment.

Dwellings in structurally sound condition, of size 75 to 110 square meters (typical two-story rowhouses in Baltimore), with at least one eligible child 6 months through 48 months who spends most of his or her time at the dwelling, were selected for the study. In addition, dwellings to be randomized for R&M interventions must contain lead-based paint and elevated dust lead levels prior to the intervention.

The expected completion date is October 1997. As of March 1994, the initial and 6 month sampling campaigns have been completed in the modern urban and previously abated houses and the 12-month campaign is in process. Pre- and immediate post-abatement sampling has been completed for 61 or the 75 R&M houses. The 2-month and 6-month campaigns are in process.

c. Dust sampling strategy and method(s)

House dust is collected with the modified High Volume Small Surface Sampler (HVS-3) cyclone vacuum sampler, sometimes referred to as the Baltimore Repair and Maintenance (BRM-HVS-3) sampler. The sampling strategy is to collect three composite floor samples per dwelling per visit. One composite sample is taken across rooms with windows on the first floor; one is across rooms with windows on the second floor; the third is composited from first and second floor rooms without windows. (Most of the dwellings in this study are two-story rowhouses with similar room layouts.) Two randomly selected 1-square foot floor locations are sampled in each of the sampled rooms. Composite windowsill and window trough samples are collected separately from all first and second floor windows available for sampling. Individual dust samples are collected from air ducts and interior and exterior entryways.

Results and Conclusions: Pending.

Major strengths: This is a randomized prospective study with control groups. Furthermore, dust sampling covers large areas of the dwelling and both lead concentration and lead loading are being measured in house dust.

Major limitations: A potential weakness for characterizing the efficacy of interventions directly with blood lead levels is that the range of children's blood lead levels is not controlled by the design of this study. In addition, the children may have had a prior elevated blood lead level and the children may not have lived in the target dwelling long enough prior to the intervention.

7.3 EPA childhood lead exposure and reduction study (CLEAR, 1994)

Objectives: To test an exposure reduction program in a randomized trial to examine its capacity to minimize the increase on blood lead levels that usually occurs in younger inner city children. The approach combines a lead control educational program with biweekly assistance in dust control.

Outcome measurement: dust lead loading and concentration measurements, blood lead levels.

Intervention: Families are randomized into a control group and an intervention group. The control group receives general health and accident prevention education, with routine information on the hazards associated with lead. The intervention group receives the foregoing information as well as intensive health education on ways to minimize lead hazards in the home. As part of this educational effort, a team of two specially trained cleaners assists the family with clean-up every 2 weeks.

Methods:

a. Design issues

study design: Prospective, Randomized

method used to select dwellings: houses a child with a blood lead level between 8 and 20 µg/dL

use of a control group : yes

duration of follow-up : the children and dust lead levels are followed for the 12-month period during which the ongoing intervention is implemented

completion of follow-up : pending.

b. General Methods: The families of children under 3 years of age with blood lead levels in the range of 8 to 20 µg/dL were recruited for the study. Families of children with blood lead levels greater than 20 µg/dL were excluded from the study because these homes are often targeted for abatements mandated by the local health department. The study is just finishing the recruitment phase (9/94) and approximately 110 families have been randomized into control and intervention groups. Baseline data, including blood lead measurements and environmental measurements of house dust, paint, water, and nearby soils, have been collected for the majority of the households. Blood and dust lead levels will be measured at each household 6 and 12 months after enrollment.

c. Dust sampling strategy and method(s) : Approximately three dust samples are collected in each home; two from floors and one from a windowsill. Typically, the kitchen floor and a floor from one other room is sampled. If bare floor is accessible in the sampled rooms, dust samples are collected with the "Lioy-Weisel-Wainman (LWW) wipe method." If only carpeted surfaces are accessible, the "Lioy vacuum method" is used. The wipe sampler is a template sampler developed at the University of Medicine and Dentistry, Piscataway, New Jersey. The sampler was designed to measure lead concentration and lead loading in dust from a 50 cm^2 area. The Lioy vacuum sampler is a small canister vacuum cleaner with an in-line conical filter to collect the dust. The filter, which is preweighed, is located just downstream from the pickup nozzle in the vacuum hose. No standards are currently available for either the wipe or vacuum sampling method used in this study. Soil sampling procedures are not known at this time.

Results and Conclusions: Pending

Major strengths: Major strengths are that this is a randomized prospective study with a control group and that both lead concentration and lead loading are being measured in house dust.

Major limitations: A potential weakness with the dust-lead measurements is that the dust sampling methods employed have not been used extensively outside of the investigators' research group and that only a few dust measurements are being collected in each home. Although this study takes place over a 12 month period, it will not measure the long-term efficacy of the dust control procedures. The study does not measure dust lead levels after the dust control teams stopped going to the dwelling every 2 weeks. Educating the family is the only sustainable experimental intervention provided.

7.4 Studies funded by the Centers for Disease Control and Prevention (CDC)

The Centers for Disease Control and Prevention (CDC) has several ongoing studies that may provide information on the short- or long-term efficacy of controlling housing-associated lead hazards. While the final results are not available, background information for each study is presented below.

Four current CDC studies, done in collaboration with EPA, are designed to measure changes in household dust and blood lead levels of lead-poisoned children following lead hazard control activities. Levels of lead in blood of lead poisoned children and in house dust are being measured before and periodically up to two years after the dwellings are treated for lead hazards according to local regulations. Changes in blood and dust lead levels will be compared to those observed in control children whose lead levels are not high enough to trigger treatment of lead hazards in their homes. Cooperative agreements to carry two of these studies were awarded in September 1991 to the Massachusetts Department of Public Health and the Maryland Department of the Environment. Subject enrollment began in early spring of 1992. In 1992, cooperative agreements for the other two studies were awarded to Trustees of Health and Hospitals of the City of Boston and to the Department of Health of the City of Cleveland. Tables 9 and 10 provide a more complete summary of these studies.

Another CDC-funded study will evaluate the efficacy of residential lead paint abatement as a means of primary prevention for lead poisoning in young children, using a matched cross-sectional study and analysis of data collected by the Massachusetts Department of Health. Finally, a study conducted by the Iowa State Health Department under the State and Community-Based Childhood Lead Poisoning Prevention Program grant program, will determine whether homeowners and landlords can safely and effectively abate lead-based paint hazards. Project staff will enroll eligible owners and landlords of 30 homes contaminated with lead-based paint and provide them with information about safe lead-based paint hazard abatement. They will collect and record blood lead levels of the adult participants before and after the abatement, and monitor lead dust before, during, and after the abatement.

Table 9. CDC-funded studies of Blood Lead Levels Following Environmental Interventions (BLLFEI): Summarized by Peter A. Briss, MD 12/94.

	Boston BLLFEI	Cleveland BLLFEI
Objectives	Measure changes in window trough and floor dust lead levels and venous blood lead levels in children with initial venous blood lead levels between 10 and 24 µg/dL who reside in housing that undergoes lead hazard reduction activities.	Measure changes in venous BLLs and house dust lead in the homes of children following limited hazard abatement (LHA).
Outcome measurements	Venous blood, window trough dust, and floor dust lead levels.	Venous blood, window trough dust, and floor dust lead levels
Intervention	The intervention involves education (in person and then by postcard), cleaning window troughs and sills with HEPA vacuum, painting troughs and sills with white paint, HEPA vacuuming hard-surface floors, and patching holes in plaster with duct tape, joint compound, or sheet rock. Carpets will also be vacuumed if visible paint chips are noted on them.	Comparison and control groups will receive Emergency Lead Hazard Reduction (ELHR) consisting of wet scrubbing or wet scraping loose or flaking paint, containment of debris, and dust clean-up as well as parent lead safety education. The intervention group will also receive Limited Hazard abatement (LHA) consisting of HEPA vacuuming, high phosphate detergent washing, wet scraping and repainting, replacing components, enclosing or encapsulating some material, and removing some lead based paint.
Methods	Daily review of Boston Childhood Lead Poisoning Prevention Program (BCLPPP) data for children who: live in the City of Boston, are <4 years old, have venous BLLs 10-24 µg/dL, live in a housing unit with lead paint in window areas (lead paint defined as paint that tests positive for lead by sodium sulfide testing), have lived at current address for 3 months, have no plans to move in the next 3 months, have no prior history of lead poisoning or chelation and are not expected to undergo chelation. Severe hazards are defined to exist when paint chips or dust in window troughs are subjectively judged severe, there are any paint chips on floors, or there are any holes in plaster walls accessible to a child Follow up BPbs, dust samples and compliance questionnaires will be done at 6,12, and 14-16 months.	1. Search Cleveland Department of Public Health (CDPH) database for children with venipuncture BLLs from 18-39 µg/dL and who are aged 12-36 months, not expected to be chelated, has lived at the same address for six months, live in a 1-2 family owner-occupied house with identifiable lead paint hazards (defined as presence of any non-intact paint measuring ≥1.0 mg/cm² by portable x-ray florescence (XRF)), whose homes have not undergone emergency lead hazard reduction. 2. Measure Pre intervention BPb. 3. Perform ELHR in all homes. 4. Perform LHA in intervention homes. 5. Perform follow up blood lead testing and environmental sampling in intervention and control homes.
Study design	Prospective Cohort	Prospective Cohort
Control group	3 groups are included in the study. Children living in households with "severe" lead hazards will be automatically assigned to an intervention group and analyzed separately. Households without "severe" lead hazards will be randomly assigned to interventions and non-intervention groups.	Children with BLLs from 23-39 are assigned to the intervention group while those with BLLs from 18 to 22 are assigned to the comparison group
Duration of follow-up	up to 16 months	Up to 2 years

Table 9. (continued)

	Boston BLLFEI	Cleveland BLLFEI
Dust sampling strategy and methods	Wipe dust samples are collected from a window trough, windowsill and hard surface floor in the kitchen, child's bedroom, and a living or play room.	Interior dust samples include: Floor dust by composite dust vacuum method (DVM) samples of carpeted and bare floors. Single or composite wipe sample from bare floors (depending on how many rooms have bare floors) and a DVM and wipe sample from a window trough composite sample collected from the entry, the room where the child most commonly plays, and the child's bedroom.
Strengths	Prospective cohort design. Measurement of both environmental data and BLLs. Study of a commonly practiced but inadequately studied intervention	Prospective cohort design. Measurement of both environmental data and BLLs. Study of a commonly practiced but inadequately studied intervention
Weaknesses	Non-random group assignment.	Non-random group assignment

Table 10. CDC-funded studies of Blood Lead Levels Following Abatement (BLLFA): Summarized by Thomas D. Matté, MD, MPH 1/95.

	Massachusetts	Maryland
Objectives	Measure changes in blood lead levels among children with elevated blood lead levels, in the levels of lead in interior dust in their homes, and in the levels of lead in soil around their homes following deleading as mandated by state regulations (intervention group). To compare these changes in blood lead and dust lead to those observed for children with elevated blood lead levels whose dwellings to not receive deleading during the follow-up period (control group).	Initially planned as a prospective blood lead study (similar to that in Massachusetts) study design was changed after difficulty identifying eligible subjects (few families of lead-poisoned children in Baltimore re-occupy dwelling where child was poisoned after it is abated). Current objective is to measure changes in dust lead loading in dwellings following "alternative abatements" ordered by the health department in Baltimore.
Outcome measurements	Changes in venous blood lead, interior dust lead loading measured by wipe sampling on floors, windowsills, and window troughs. Changes in soil lead concentration near foundations in intervention group only.	Changes in dust lead loading on surfaces "cleared" following abatement, including a variable combination of floors, windowsills, and window troughs, depending upon the initial violations and scope of work.
Intervention	Stripping, enclosure, or replacing all interior and exterior components with peeling or loose leaded paint (>1.2 mg/cm² by xrf or positive sodium sulfide); for windows with sills 5 feet or less from the floor -removal of all leaded paint from all parts of window that are movable or contact movable parts or window replacement; removal of all leaded paint from accessible, mouthable surfaces below 5 feet or replacement of the building components. Prohibits certain removal methods. Requires occupant exclusion, interior containment, and HEPA, TSP, HEPA cleanup. Clearance dust testing at discretion of inspector.	Following visual inspection and selected dust wipe sampling: elimination of code violations contributing to lead hazards; window treatments to eliminate abrasion of leaded surfaces; treatment of doors and frames to eliminate abrasion of leaded surfaces; treatment of floors and stairs to create cleanable surfaces and reduce wear and friction; elimination of all carpeting and rugs where possible; repair and repainting of all corrected interior and exterior chipping and peeling surfaces; thorough post-abatement cleanup; clearance wipe testing in treated areas; periodic reinspection and dust testing.
Methods	Families of children whose blood lead levels usually trigger prompt inspection and abatement (initially 25-34µg/dL, lowered to 20-34 µg/dL in mid study) identified from Mass CLPPP data are contacted immediately and to assess eligibility and offer enrollment. Families of children with elevated blood lead levels which would not trigger mandated inspection and abatement (initially 15-24 µg/dL, lowered to 15-19 µg/dL in mid-study) identified from Mass CLPPP data are contacted approximately 6 months after their blood lead measurement. Eligibility criteria for all participants include: <6 years of age, expected to remain in dwelling for 12 months, not treated with chelating agents, no previous history of lead poisoning. Result is cohort of enrolled children, some of whom received prompt deleading (intervention group) and were then followed and others who did not receive deleading during the follow-up period (control group). The initial selection process was designed to achieve as similar blood lead levels as possible between the intervention and control groups within the constraint of legally mandated inspections and abatements for lead-poisoned children. In fact, because of delays complying with abatement orders among children with blood lead levels 20-34 and some abatements occurring in dwellings of children with lower blood lead levels, a fair amount of overlap in baseline blood lead levels for the intervention and control groups has been obtained. Follow-up blood lead testing is to be performed at times corresponding to roughly for 2, 6, and 12 months post deleading and at similar intervals for the control group. Dust lead testing is to be conducted pre-abatement and 2 and 12 months post-abatement.	Of 186 lead abatement projects identified by the Baltimore City LPPP from January 1, 1991 through June 30 1992, 89 were selected that met criteria for inclusion within the initial prospective blood lead study and 72 of these had undergone alternative abatements (as described above, not requiring removal of all lead paint). Records were reviewed to identify clearance dust lead measurements and follow-up measurements performed approximately 6, 12 and 18 months post clearance. Where follow-up measurements were pending, an effort was made to access the property to collect these. Dust lead data are being analyzed to quantify reaccumulation or other changes in average floor, sill, and well lead loadings measured following abatement and to assess factors such as room type or floor of building that might influence reaccumulation.
Study design	Prospective cohort	retrospective cohort
Control group	See methods	none

	Massachusetts	Maryland
Duration of follow-up	12 months	up to approximately 19 months
Dust sampling strategy and methods	In kitchen, child's bedroom, and living room or playroom, 2 floor, 1 windowsill and 1 window trough sample obtained by wet wipe.	varied depending upon violations
Strengths	Prospective cohort design.Intervention being studied is "real-world" legally-mandated one being carried out by a variety of contractors.	Intervention being studied is "real-world" legally-mandated one being carried out by a variety of contractors.
Weaknesses	Non-random assignment of treatments.	Non-random assignment of treatments. No control group. No blood lead measurements

Table 10. (continued)

8. Summary of Findings

This report reviewed published and unpublished intervention studies on the efficacy of controlling lead-based paint hazards in housing. While the interventions and methods used to assess efficacy differ greatly, there are three general types of studies that can be identified:

1) the large demonstration projects conducted by HUD (HUD, 1991b, 1993, 1994b) and Jacobs et al. (1992), that use methods similar to those in the HUD interim guidelines and that focus on dust lead levels as the primary outcome. These studies evaluate costs, feasibility, worker protection, containment and clean-up, but not the duration of hazard control following routine use of the dwelling.
2) the smaller pilot projects conducted by Farfel et al. (1991, 1994a) that focus on the short- and long-term effect of comprehensive abatement procedures on dust lead levels; and,
3) the retrospective studies or intervention trials that evaluate the short- and long-term efficacy of interim controls to reduce blood lead levels. Only one study (Farfel, 1990) evaluated both blood and dust lead levels as an outcome measure.

Only one study attempted to evaluate changes in both blood and dust lead levels following a single intervention (Farfel, 1990) and this study had problems with completeness of follow-up (19%) because blood lead measurements were obtained at the discretion of the child's health care provider, and measurements that followed chelation were excluded from the analysis. Furthermore, none of the studies individually **compare** the short- and long-term efficacy of the current HUD-recommended abatement procedures with current interim control techniques. Thus, no scientific data is available to ascertain the most cost-effective lead hazard control method(s) for reducing lead hazards after the intervention and after "normal" household use. Two of the ongoing prospective studies (Lead-Safe Housing, 1994; Farfel, 1994b) are comprehensively examining these issues, but the results will not be available for two to three years.

However, taken as a group, the studies demonstrate that a range of abatement and interior control procedures are likely to be effective in reducing dust level and/or blood lead levels in children.

Despite numerous gaps in the data, sufficient evidence exists that indicates lead hazard control interventions can be done safely with adequate cleanup. However, the short- and long-term impact on lead hazards has not been fully characterized.

8.1 Efficacy of worker protection, containment, and clean-up

Although none of the abatement demonstration projects had complete information on the blood lead levels of workers, they all report that no significant increases were observed before to after abatement. Even though some lead hazard control activities may increase ambient and personal air lead levels (HUD, 1991b), technology is available to prevent adverse exposure among workers. The information from the demonstration projects may be useful for determining the need for personal protection during future lead hazard control activities.

Containing lead hazards during the abatement process is an important step for conducting a "safe" abatement. The three demonstration projects (HUD, 1991b, 1993, 1994b; Jacobs, 1992) followed interim HUD guidelines and did not significantly contaminate areas adjacent to the worksite, although there is some concern about an increase in the mean soil lead level from 755 to 867 µg/g at one project site (HUD, 1991b), and an increase in the mean dust lead levels in adjacent dwellings of 62 µg/ft² at another project site (HUD, 1994b). Although no children were tested to evaluate containment, the HUD guidelines do not allow children within the work area during the abatement process. In contrast, the study by Amitai et al. (1991) demonstrates the impact of interim control procedures conducted in 1984 and 1985 when containment standards were apparently not adequate, and children were not routinely kept away from the work area. They found that the children's average blood lead level increased by 5.7 µg/dL (a 16 percent increase) during the time period when "deleading" was underway. Dry scraping and sanding and the use of torches to soften paint for scraping were associated with the largest increases in blood lead levels.

Several of the studies, particularly Farfel, 1991, showed that low dust lead levels can be established after the lead hazard control activities and clean-up are complete. The studies report several factors that influence the ability to clean up the lead dust that is released by the deleading process and, thus, ensure that children do not move back into grossly contaminated dwellings. For example, the method of abatement was associated with the ability to meet clearance standards (HUD, 1991b). The on-site removal methods that generate significant amounts of dust or do not remove all the lead from the substrate, tended to have the highest failure rates. Specifically, clearance testing that followed on-site chemical stripping and hand-scraping with a heat gun had the highest failure rates, while encapsulation and replacement hazard control methods had the lowest failure rates (HUD, 1991b). In addition, the researchers note that proper containment and daily clean-up, trained workers, and smooth cleanable surfaces influence the ability to achieve low residual dust lead levels after clean-up. At Murphy Homes, the contractor reported that the most common reason for repeated cleaning was that a new worker had been put on the job, and on-the-job training usually rectified the problem. Finally, exterior surfaces made of old porous concrete, such as steps and porch floors, often failed to meet the interior floor clearance lead dust standards.

Since the immediate post-intervention dust lead levels are influenced by the factors mentioned above, and are not necessarily related to the potential for reaccumulation of leaded dust, post-intervention dust lead levels do not measure the short- and long-term effect of the intervention after "normal" household use. Several studies (Weitzman, 1993; Farfel, 1990, 1991, 1994a; Charney, 1983) that evaluated methods from minimal to comprehensive abatements showed that dust lead levels decreased after cleaning compared to the pre-intervention levels. However, the dust lead levels increased again over time with "normal" use, albeit not always back to baseline (Weitzman, 1993; Farfel, 1994a). Finally, while it is reassuring to document that dust lead levels are below the HUD clearance standards after the intervention is completed, it is important to know the pre-intervention dust lead levels to ensure that levels were not even lower to begin with and, may in fact, have actually increased. This information is not available in several of the studies reviewed.

8.2 Duration of Hazard Control

While there is favorable evidence about the efficacy of worker protection, containment, and clean-up practices specified in the HUD abatement guidelines, there are gaps in our knowledge about the short- and long-term effects of these abatement. Concerning comprehensive abatements, only two studies evaluate the long-term effects on dust (Farfel, 1991, 1994a), and no studies evaluate either the primary or secondary effect of comprehensive lead hazard abatement on blood lead levels. The intervention studies that evaluate effects on blood lead levels only concern soil abatement or interim control procedures that address paint and dust lead hazards.

8.2.1 Effect on dust lead levels

As shown in Table 11, the studies that provide information about the short- and long-term effects of interventions on dust lead levels are all conducted in Baltimore, Maryland by one research group (Farfel, 1990, 1991, 1994a). These studies use the same dust wipe sampling procedures and, presumably, have similar ambient lead levels in the environment neighboring the dwellings. These factors contribute to the comparability between these studies.

The traditional and modified traditional "abatements" used by Farfel are considered interim controls by Title X standards. In fact, these two interventions did not address lead hazards in window troughs. The other two abatement studies evaluate procedures that are more comprehensive and similar to those recommended in the

HUD guidelines (HUD, 1990). The long-term effect of the two interim control procedures were not very different, nor were they favorable, which is probably due to inadequate containment, clean-up, and incomplete removal of lead hazards. In contrast, the long-term effect of comprehensive abatements was a dramatic decrease (greater than 80 percent) in mean dust lead loading at six to nine months after the intervention (Farfel, 1991). This decrease was sustained up to 1½ to 3½ years after a similar kind of comprehensive abatement intervention (Farfel, 1994a) (Table 11).

Table 11. The Long-Term Effect of Lead-Based Paint Hazard Control as Measured by Dust Lead Levels.

	Baltimore traditional (Farfel, 1990)	Baltimore modified traditional (Farfel, 1990)	Baltimore experimental (Farfel, 1991) *	Baltimore follow-up (Farfel, 1994a)*
Intervention (using the Title X definitions)	Interim control without comprehensive clean-up	Interim control without comprehensive clean-up	Abatement	Abatement
Year of intervention	1984-85	1984-85	1986-87	1988-91
Number of dwellings	44	15	6	13
Duration of follow-up	6 months	6 months	6 - 9 months	1.5 - 3.5 years
Geometric mean dust lead loading (µg Pb/ft²) by surface type:				
Floors:				
pre-intervention	251	288	520	251
at follow-up	316	316	56	37
% change at follow-up	26% increase	10% increase	89% decrease	84% decrease
Windowsills:				
pre-intervention	1,338	1,803	4,610	1,041
at follow-up	1,543	1,636	409	102
% change at follow-up	15% increase	9% decrease	91% decrease	90% decrease
Window troughs:	†	†		
pre-intervention	15,504	18,283	29,437	14,221
at follow-up	12,474	24,892	1,004	604
% change at follow-up	20% decrease	36% increase	97% decrease	96% decrease

* Although these abatements were conducted before the HUD interim guidelines were issued in 1990, the abatements were comprehensive and include many of the guidelines provisions for worker protection, containment and clean-up.

† The traditional and modified traditional procedures did not address lead paint hazards in window troughs.

8.2.2 Effect on blood lead levels

As shown in Table 12, all the studies show a decline in the average blood lead level over time. The studies indicate that on average, lead hazard control procedures are generally beneficial to lead-poisoned children. The findings of these studies differ with respect to the magnitude of the benefits, with an estimated decline in blood lead levels obtained 6 or more months after lead hazard control ranging from 0.54 µg/dL (a 4 percent decline) (Weitzman, 1993) to 10.2 µg/dL (a 29 percent decline) (Amitai, 1991).

When assessing the impact of interventions on blood lead levels, the studies have major limitations that may bias the estimated effect of the intervention either up or down. The effect of the intervention on blood lead levels may be *underestimated* if the study uses follow-up measurements obtained at the health care provider's discretion (Farfel, 1990; Staes, 1994; Amitai, 1991; Schultz and Murphy, unpublished; Swindell, 1994). This is a particular concern when researchers use existing lead poisoning prevention program data retrospectively. The decline in blood lead levels may be underestimated because children with less reduction in the blood lead levels (poorer outcome) may be more likely than those with better reductions to have follow-up measurements recommended by their health care provider. Staes et al. (1994) found that children with blood lead measurements approximately one year after diagnosis had less rapid early declines in blood lead levels than those without follow-up data. Finally, the impact of *current* lead hazard control activities may be underestimated because most of the studies we reviewed evaluate interim control procedures conducted before 1990, when the dangers of unsafe practices were less widely known and the HUD interim guidelines had not yet been published (Figure 1).

The effect of the intervention on blood lead levels may be *overestimated* if the study includes children who have received chelating agents for provocative tests or treatment (Rosen, 1991, 1993; Amitai, 1991; Charney, 1993). It may also be overestimated if the study does not include control subjects living in dwellings where lead hazards have not been controlled (Farfel, 1990; Amitai, 1991; Rosen, 1991, 1993). Some changes in blood lead levels attributed to environmental interventions may, in fact, be due to secular trends, maturing of the children, regression to the mean, education of the parents to improve housekeeping behaviors, or a combination of these factors. In one study (Staes, 1994), half of the decrease in blood lead levels observed among children whose houses had been treated was seen among children living in homes that were not treated. In addition, two studies found that blood lead levels decreased following educational interventions alone (Murphy and Schultz, unpublished; Kimbrough, 1994).

The benefits of interim control procedures without comprehensive clean-up provisions may be greatest among lead-poisoned children with higher blood lead levels (Charney, 1993; Staes, 1994; Swindell, 1994). Staes et al. report that children in St. Louis with blood lead levels $\geq$35 µg/dL may be exposed to poorer housing conditions, ingest more paint chips or lead-contaminated dust. Their average blood lead level declined 22 percent relative to the change in the comparison population. These conditions, which result in higher dose exposures, can be partly corrected by the hazard control strategies that were required by the St. Louis City Health Department. Only minimal benefits of lead hazard control were apparent among lead-poisoned children with initial blood lead levels of 25-34 µg/dL (their blood lead level declined only 1 percent relative to the change in the comparison population). Lead hazard control procedures like those performed in St. Louis are conducted in other cities in response to children with blood lead levels as low as 15-20 µg/dL. As the blood lead levels that trigger prevention activities are lowered, the above findings suggest that cities will need to require that lead hazard control activities be more extensive than that performed in St Louis in 1989 to 1991. The activities should follow the procedures described in the new HUD guidelines (HUD, 1994a), which include more complete lead hazard control, rigorous clean-up procedures, training and protection of the workers, and relocation of children during the remediation process.

While retrospective studies have been useful, they have important limitations and potential biases. Several prospective studies of various standardized lead hazard control strategies are currently being conducted. These studies use control populations, ensure complete follow-up, and measure environmental exposure. Thus, the results from these studies should help fill in the gaps of our current knowledge.

Table 12. The Long-Term Effect of Lead-Based Paint Hazard Control as Measured By Blood Lead Levels.

Intervention title (years implemented)	Duration of follow-up	Percent of children having follow-up in each study	Number of children in each study group	Source of lead targeted for hazard control*	Mean blood lead levels (µg/dL)		
					Pre-intervention	Decline at follow-up	Percent decline in blood lead level at follow-up
Baltimore traditional vs. modified (1984-85)	6 months post intervention	19%	29	paint	32.5	1.9	6%
Baltimore dust control (1981-82)	†	63%	14 35	dust no treatment	38.6 38.5	6.9 0.7	18% 2%
Boston Retrospective (1984-85)	8 months post intervention	52%	59	paint	35.7	10.2	29%
St Louis Retrospective (1989-90)	10-14 months post diagnosis	28%	37 17	paint no treatment	35 35	8.2 4.2	23% 12%
Worcester County retrospective (1987-90)	up to one year post intervention	68%	132	paint	25.9	4.8	18%
New York chelation (1989-91)	6 months post intervention	>90%	87	paint	27	6 §	22%
Boston three-city soil (1989-90)	11 months post intervention	98%	52 51 47	soil, dust, paint dust, paint paint	13.1 12.4 12.0	2.44 0.91 0.52	19% 7% 4%

* All of the paint hazards were treated with interim control procedures to stabilize paint hazards. The only study that fully abated a lead hazard was the Boston three-city soil study, where soil hazards were addressed.

† The cleaning was done twice per month for a 12 month duration, with concurrent follow-up

§ All the children in the New York study received provocative chelation, but did not undergo chelation treatment.

8.3 Implications for primary prevention of childhood lead poisoning

Since all of the children enrolled in the identified intervention studies were chronically exposed to lead hazards, and thus may have large body burdens of lead, their blood lead levels will take a long time to equilibrate to a lead hazard-free environment. This may explain the modest decreases observed in follow-up blood lead measurements in the studies reviewed. However, the increase in blood lead levels *prevented* by these lead hazard control interventions may be larger than the decrease measured among already poisoned children.

Title X is aimed at making primary prevention of lead poisoning a reality rather than simply responding to already poisoned children. Abatement and interim control procedures should control lead hazards so both current *and* future residents are not exposed to lead. Abatement procedures that remove lead from the dwellings should avoid re-exposing future residents altogether. Unfortunately, the expense of full abatement is great and limits the number of lead-hazardous units that society can afford to address. Interim control procedures that isolate or stabilize lead hazards, but do not entirely remove the lead from the dwelling, may pose a threat to future residents if proper follow-up provisions are not adopted. However, future residents may have a heightened level of awareness of the existing potential lead hazards and take appropriate precautions during future construction activities. Cost-effectiveness analyses need to address these issues and account for both the reduction in blood lead levels among lead-poisoned children and the prevention of lead poisoning among future residents at the dwelling. The largest impact of lead hazard control interventions may be for future residents.

9. Research Needs

Today, several well designed prospective studies are underway to better quantify the impact of various lead hazard control strategies on blood and dust lead levels, and to evaluate their cost-effectiveness. However, a number of important areas are not being examined. For example, there is a need to conduct:

- an evaluation of differences in dust sampling strategies used to assess efficacy (e.g., composite sampling Vs. single surface sampling),
- an evaluation of the use of the HUD dust clearance standards after lead hazard control work but prior to further rehabilitation work, and
- the development of low-cost standard models that state or local housing programs can easily incorporate into their ongoing activities that will provide uniform information to assess efficacy.

These three issues are discussed in more detail in subsequent sections of this report. The National Center for Lead-Safe Housing has identified additional research needs related to this report, including an evaluation of:

- the Long-Term Efficacy of Lead-Based Paint Hazard Control (including both abatement and interim control).
- National Survey of the Prevalence of Lead-Contaminated House Dust.
- Determination of the Utility of the Standard HUD Risk Assessment and Risk Assessment Screen Protocols.
- Review of Existing Data on the Relationship Between Dust Lead and Blood Lead.

- Effectiveness of Different Dust Control Methods.
- Contribution of Carpets and Upholstered Furniture to Childhood Lead Exposure.
- Dust Settling Following Abatement.
- Contribution of Friction and Impact Surfaces to Dust Lead.
- Occupational Exposures for Workers in Remodeling and Renovation.
- Evaluation of Inexpensive Technologies for Testing Lead in Paint and Dust.
- Effectiveness of Encapsulation and Paint Film Stabilization. It is not known whether or not newly-developed encapsulants are more durable that ordinary paint, and whether or not these two relatively inexpensive methods are effective in controlling childhood lead poisoning. This study would compare these two coating systems for longevity and other variables and would compare them to other abatement procedures.

9.1 Measuring lead in dust

Many studies show a blood lead/dust lead relationship in children. However, scientists do not agree on the best way to measure lead in house dust. Results from one method are unlikely to be directly comparable to results from other methods. Furthermore, results from the same method used in two settings may differ greatly if the sampling strategies are different. When assessing the impact of lead hazard control activities on dust lead levels, it is important to understand the method and strategy of sampling, particularly when comparing results from several studies.

Two fundamentally different technologies, wipe and vacuum sampling, are available to sample house dust. There are also two common measures of lead in dust: lead concentration and lead loading. Lead concentration, sometimes called a mass concentration, is usually expressed as micrograms of lead per gram of dust (µg/g) or the equivalent expression, parts per million lead by weight (ppm). Lead concentration is a measure of how much lead is in the dust. Lead loading, sometimes called area concentration, is usually expressed as micrograms of lead per square area of surface ($\mu g/m^2$ or $\mu g/ft^2$). Lead loading is a measure of how much lead is on a surface.

Common wipe sampling methods measure lead loading directly, without measuring lead concentration. Vacuum sampling techniques measure both lead loading and lead concentration. To date, no scientific studies have compared the merits of measuring dust lead concentration, lead loading, or both, for determining the long-term efficacy of lead hazard control interventions. While empirical evidence shows that cleaning can, at least in the short run, reduce lead loading levels in dwellings, there is little or no evidence that the concentration of lead in house dust can be reduced over a short period of time. However, lead dust concentrations may decrease in the long run after hazard control interventions are implemented. This possibility has not been tested.

For clearance testing, which measures dust lead levels immediately after an intervention, most people would agree that lead loading is the appropriate unit of measure. This is because lead loading measures how much lead is on a surface; and the purpose of clearance testing is to ensure that workers have adequately cleaned the work area of dust and debris generated from the intervention process. Clearance testing results do not necessarily measure the potential for re-accumulation of leaded dust.

Two studies that evaluated large abatement projects highlight the fact that clearance testing indicates only that cleanup was adequate; it does not indicate the potential for re-accumulation of dust lead hazards (Jacobs, 1992 and HUD, 1991b). The report for the HUD study states:

> "A direct factor in the efficacy of the cleanup process was the attention of the abatement contractor to several factors, including adequate sealing of surfaces with polyethylene sheeting prior to abatement, proper daily cleanup practices, and attention to detail...In instances where poor worksite preparation was employed, additional cleaning was often required to meet the clearance levels."

In addition, since clearance tests are not indicative of normal household use, it may be inappropriate to use clearance test results, compared with pre-intervention dust lead levels, to conclude that interventions reduced lead-based paint hazards. The accumulation of dust and lead in a dwelling depends on the rate of dust generation by particular sources, the lead concentration in the dust being generated, the tendency for surfaces to trap leaded dust particles, which is related to the effect of normal housekeeping or dust lead. The short- and long-term efficacy of interventions that target potential lead sources and/or make surfaces cleanable should be assessed after routine household use.

The sampling strategy used to measure lead levels is important to consider and varies among intervention studies. One such strategy, composite sampling, is a technique that yields a weighted (by surface area) arithmetic average lead measurement of two or more samples by physically combining the individual samples collected in the field into one sample. Composite sampling is typically used to collect dust from many areas of a dwelling for the cost of only a few laboratory analyses. Composite sampling strategies can also be designed to reduce the spatial variability (e.g., the variation of lead dust levels across a floor) in lead dust measurements. For example, several one-square foot samples can be collected from the same room and composited for analysis.

Little research has been done to examine variability in lead dust loadings or concentrations across a floor within a room, between different rooms of a dwelling, or between components, such as window troughs and sills. Thus, it is not clear if sampling from one location -- from one-square foot floor area or one windowsill -- can accurately characterize the lead dust levels across other locations. Assuming that variability is great, composite sampling, by providing a weighted arithmetic average of lead levels across the subsampling locations, may provide a cost-effective means of reducing the spatial variability in lead dust measurements.

A common criticism of composite sampling is that lead variation across a floor or throughout a residence cannot be determined; lead "hot spots" may be missed. It must be acknowledged, however, that any sampling strategy may miss hot spots. The important issue is how much these hot spots contribute to the total lead exposure of the average mobile child or to the issue of efficacy. This question has not been answered by scientific studies. In any case, the statistical relationships between blood lead levels and the average lead dust levels across large areas in which children play and crawl are likely to be more significant than the relationship between blood lead levels and a potential high-dose source of lead exposure for a short- period of time (i.e., from a lead hot spot). The researchers Davies et al. (1990) used this assumption to design a sampling strategy that collected dust "taken over all the exposed floor surface in the rooms concerned" (thus, the average floor dust lead level was measured in a room) rather than from small areas in the rooms, such as one-square foot, and found relatively high statistical correlations with children's blood lead levels (r=0.46). The Trail lead study, mentioned earlier, also found higher statistical correlations between lead loadings measured from a whole house floor composite sample collected with a HEPA vacuum cleaner, than from samples collected with a common house dust sampler from small areas in a few rooms (Trail, 1994).

If future research indicates that the average dust lead measurements in a residence most accurately predict children's blood lead levels, then average measurements may also be the most appropriate for assessing the efficacy of lead hazard control interventions. Remembering that the cost of follow-up dust measurements is important for the success of implementing an efficacy study, composite sampling strategies may be the most economical way to measure these averages.

9.2 Use of the HUD dust lead clearance standards

The HUD dust lead clearance standards were designed to decrease the chance that children who move back into dwellings after lead hazard control interventions will be exposed to high dust lead levels. However, extensive modernization work, which may re-contaminate the dwelling with leaded dust, sometimes follows lead hazard control work before re-occupancy. Scientists should evaluate whether it is appropriate for the HUD dust clearance standards to be met after lead hazard control work is completed but before modernization work is conducted. While leaded dust generated during lead hazard control work needs to be cleaned to protect adult workers conducting further rehabilitation work, it may not be necessary to meet the level of protection afforded by the HUD clearance standards. It may be appropriate to meet the clearance standards only once -- immediately prior to re-occupancy. By analyzing dust lead levels prior to lead hazard control interventions, immediately after clean-up, and immediately prior to re-occupancy, we would have a better understanding of the potential for re-accumulation of dust hazards following modernization of an already lead-controlled dwelling and whether it makes sense to require that the HUD clearance standards be met prior to further rehabilitative work.

9.3 State and Local Programs

Many state and local health and housing programs are actively conducting lead hazard control interventions in the nations housing stock to control lead-based paint hazards. However, it is difficult to assess the efficacy of their efforts. A standard low-cost model for programs to follow is needed to use this potential wealth of useful information. The Milwaukee Health Department has developed a program that collects additional dust-lead and blood-lead samples as a part of routine field practices (described in Section 6.1 of this report). The practices reflect a mixture of lead hazard control activities including education, interim controls, and abatements. It is possible that when Milwaukee's endeavors are fully characterized and published, other state and local programs could adopt the same proactive approach to evaluating the effectiveness lead hazard control interventions.

Goodman proposed a prioritization scheme that has not yet been implemented (Goodman, 1993).

10. Conclusions

1. If interior and exterior painted surfaces are stabilized, underlying causes of paint deterioration are corrected, horizontal surfaces are made smooth and cleanable, bare soil is covered and dust lead levels are brought down to acceptable levels, it is likely that lead dust levels can be controlled over time with normal housekeeping and maintenance.

2. The blood lead studies all show declines in blood lead levels following hazard control, although some of the declines are modest. The interventions used in those studies are less stringent than the current standards. Therefore, it is reasonable to expect that the current state-of-the-art lead hazard control practices will be more beneficial to already lead-poisoned children.

3. The increase in blood lead levels *prevented* by lead hazard control interventions is probably larger than the decrease measured among already poisoned children.

4. Based on the empirical evidence from numerous research projects described in the literature, it can be concluded that a broad range of hazard control strategies can bring household dust lead levels down to the clearance levels established by the United States Department of Housing and Urban Development (HUD).

5. While any single source of lead may be the major cause of lead exposure for a particular child, house dust is considered the most significant exposure source for the majority of children in the United States. Thus, current hazard control strategies ultimately aim to reduce the dust lead levels on surfaces to acceptable levels, by addressing defective paint, bare soil, and dust itself.

6. To be successful, hazard control strategies must be carried out carefully and must generally follow the practices described in the 1995 version of the HUD guidelines (HUD, 1994a). If hazard control practices are conducted haphazardly by untrained workers and contractors, dust lead levels will likely increase inside the dwelling and be difficult to clean to acceptable levels.

7. Practices, such as extensive dry scraping or sanding, open flame burning, uncontrolled power sanding, sand blasting, or water blasting of lead painted surfaces, create large amounts of leaded dust which can cause lead poisoning of workers and occupants. Studies show that these practices make effective clean-up very difficult.

8. Worker and occupant protection precautions, including sealing off work areas and properly covering floors, furniture, radiators and vents, must be taken because leaded dust will be generated by the lead hazard removal procedures. These precautions are necessary 1) to avoid poisoning workers, 2) to avoid contaminating the furnishings and the area outside the work environment, and 3) to facilitate clean-up efforts.

9. Careful and thorough clean-up and clearance is necessary to ensure that dust generated by the lead hazard removal procedures themselves are controlled and that dust lead levels are acceptable for reoccupancy of the dwelling.

10. The only way to determine that surface dust lead levels are acceptable is to collect dust samples. Dust samples can be collected using either a wipe or vacuum sampling method, and should be analyzed by an accredited laboratory to ensure the results are reliable. At the current time, only standards for wipe sampling are available. Interpretation of vacuum samples is hampered by the absence of standards.

Dust lead measurements cannot be made with the naked eye. Surfaces that appear equally dusty can have drastically different levels of lead dust on them. All of the current research studies that are examining the efficacy of lead hazard control work are relying heavily on the results from dust sampling. Visual appearance alone will not suffice to determine if the most significant lead exposure source for the majority of children, lead dust, has been reduced to acceptable levels.

11. Current prospective studies are underway to determine what the most cost-effective hazard control treatments are and for how long the dust lead levels are likely to continue to be acceptable. Studies are also examining what levels of maintenance are needed to prevent reaccumulation of excessive levels of lead in household dust after particular lead hazard control strategies have been implemented. It is likely that the necessary level of maintenance will vary depending on several factors, including the hazard control strategy used and the levels of lead in exterior dust and soil.

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