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Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on the First Year of Follow-up

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LEAD-BASED PAINT ABATEMENT AND REPAIR AND MAINTENANCE STUDY IN BALTIMORE:

FINDINGS BASED ON THE FIRST YEAR OF FOLLOW-UP

Technical Branch
National Program Chemicals Division
Office of Pollution Prevention and Toxics
Office of Prevention, Pesticides, and Toxic Substances
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CONTRIBUTING ORGANIZATIONS AND ACKNOWLEDGMENTS

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Kennedy Krieger Research Institute (KKRI)

KKRI was responsible for the overall design and conduct of this study, including the field, laboratory and data analysis activities, and the preparation of this report. The KKRI investigators were Mark R. Farfel, Sc.D., Project Director and J. Julian Chisolm, Jr., M.D. The Johns Hopkins University co-investigators were Peter S.J. Lees, Ph.D., Department of Environmental Health Sciences, and Charles Rohde, Ph.D., Department of Biostatistics. Study staff included William Derbyshire, Project Manager; Brian Rooney, Data Analyst; Desmond Bannon, Trace Metals Laboratory Supervisor; Pat Tracey, Outreach Coordinator; and Ken Watts, R&M QC Officer. Field staff were Eula Kemmer, Earnestine Powell, Tammy Smith, and Marc Talley. Laboratory staff included Mike Burns, Mavis Harby, Lori Losh, Catherine Murashchik, and Becky Zapf.

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US Environmental Protection Agency

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EXECUTIVE SUMMARY

In recent years, there has been growing interest in the use of interim measures to temporarily control the problem of extensive residential lead-based paint hazards in U.S. housing in a cost-effective manner. Title X of the Housing and Community Development Act of 1992 (P.L. 102-550) defined interim controls as " a 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 of management and resident education programs." The 1995 HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* provide detailed information on interim control practices. However, little is known about the short-and long-term effectiveness of these approaches in terms of reducing lead in dust and in children's blood.

This report presents the first year of follow-up of the Lead-Based Paint Abatement and Repair & Maintenance (R&M) Study in Baltimore. The study is designed to characterize and compare the short-term (two to six months) and longer-term (12-24 months) effectiveness of three levels of interim control interventions (R&M I-III) in low-income housing where children are at high risk of exposure to lead in dust and paint. The study has two control groups -- urban houses built after 1979, and presumably free of lead-based paint, and previously abated houses that received comprehensive abatement in the past. The study population consists of non-Hispanic black households with at least one participating child. At the outset, mean ages of study children ranged from 25 months to 33 months across groups, and their geometric mean blood lead concentrations were 10 μg/dL in R&M I, 14 μg/dL R&M II, 14 μg/dL in R&M III, and 13 μg/dL in the previously abated houses. The geometric mean blood lead concentration in children in the modern urban houses was 5 μg/dL, a value slightly above the geometric mean of 2.7 μg/dL for all U.S. children aged 12 to 60 months.[1]

During the first year of follow-up, objectives related to enrollment, laboratory performance, data quality and data completeness were met. Furthermore, families were informed by letter of the results of dust lead and blood lead tests from each campaign. For this reason, the study intervention was a combination of R&M work and the provision of information to families on a periodic basis. The main findings based on dust lead and blood lead data from the five study groups collected during the pre- and post-intervention campaigns, as well as during the two, six and 12 months post-intervention data collection campaigns are summarized below.

- All three levels of R&M intervention were associated with statistically significant reductions in house dust lead loadings and in total dust loadings. These loadings were sustained below pre-intervention levels during the first year of follow-up. Dust lead concentrations were significantly reduced following intervention in the middle (R&M II) and high (R&M III) intervention houses, but not in the low intervention houses (R&M I).

- The dust lead loadings, lead concentrations, and dust loadings during the first year of follow-up were related to the intensity of the intervention. Immediately following intervention and at two months, six months, and 12 months post-intervention, dust lead loadings, lead concentrations and dust loadings were lowest in R&M III houses, intermediate in R&M II houses, and highest in R&M I houses. Statistically significant differences were found between R&M groups on these dust measures over time. For example, at 12 months post-intervention, weighted average dust lead loading estimates were 21-fold higher in R&M I houses than in R&M III houses, and five-fold higher in R&M I houses than in R&M II houses.

- The modern urban control group had significantly lower dust lead loadings and concentrations across time than the other four groups. These houses, located in clusters of urban houses built after 1979, were expected to reflect the lowest residential and ambient lead levels in the urban environment. Low dust lead concentrations (geometric mean ≤310 μg/g, equivalent to ≤0.03 percent) and soil lead concentrations (geometric mean ≤75 μg/g) support the presumption the these houses were free of lead-based paints. Dust lead levels in the previously abated control houses three years to five years post-abatement were generally intermediate between those in R&M II and R&M III houses at the end of the first year of follow-up.

- At the end of the first year, the unadjusted geometric mean blood lead concentrations were lower for each group -- 8 μg/dL in R&M I, 11 μg/dL in R&M II, and 12 μg/dL in R&M III, 12 μg/dL in previously abated, and 3 μg/dL in modern urban. Children in the modern urban group had significantly lower blood lead concentrations over time, compared with each of the other four groups; their blood lead concentrations were <10 μg/dL, the Center for Disease Control's level of concern.

- Using <u>all five study groups</u> in the longitudinal data analysis, a statistically significant relationship was found between a composite measure of house dust lead in an entire house (both concentration and loading) and children's blood lead concentration, controlling for covariates including age and season.

- Children with pre-intervention blood lead concentrations ≥20 μg/dL had statistically significant reductions in blood lead concentration during follow-up, controlling for age and season. Statistically significant blood lead changes were not found in children in the three R&M groups with pre-intervention blood lead concentrations <20 μg/dL, again controlling for age and season. Cumulative body lead burden and neighborhood housing characteristics are discussed as two factors that may have mediated children's blood lead responses to the R&M interventions and contributed to the differences in blood lead concentrations observed between children in the modern urban group and those in the other four groups.

The next report will investigate changes in blood lead and dust lead during the second year of follow-up. It should be emphasized that the R&M interventions under investigation are interim control or partial abatement approaches to reducing lead-based paint hazards. As such, they are not expected to be as long-lasting as comprehensive abatement. During the first year of follow-up, none of the interventions in individual houses failed, that is, all or most of the dust samples showed lead loadings at, or below, pre-intervention levels. Thus, a major study objective with important policy implications remains the documentation of the longevity of the R&M interventions. It is also important to note that the costs of the interventions in this project may not be generalizable to other settings and time periods.

1.0 INTRODUCTION

This report presents the results of the first year of follow-up in the Lead-Based Paint Abatement and Repair & Maintenance (R&M) study in Baltimore, conducted by the Kennedy Krieger Research Institute. The study is a longitudinal trial of housing interventions designed to reduce children's exposure to lead in paint and settled dust in their homes.[2] Baseline demographic, environmental, and biological data were reported previously for the five groups of houses and residents studied, which included houses designated for R&M intervention levels I through III, modern urban control houses built after 1979, and previously abated control houses that had received comprehensive abatement.[3] This document represents the first report on changes in lead levels in settled house dust and children's blood associated with the three levels of interim control interventions under investigation (R&M I-III, Table 1). These interventions and the comprehensive abatements are described in section 4.2. The next report will include findings from the second year of follow-up.

At baseline, the study population consisted of non-Hispanic black households (140 children in 107 houses) with low-to-moderate monthly rents or mortgages who resided in city rowhouses. Mean ages of children studied ranged from 25 months to 33 months across the groups. Initial geometric mean blood lead concentrations were 10 μg/dL in the R&M I group, and 14 μg/dL in both the R&M II and R&M III groups, and 5 μg/dL in the modern urban group and 13 μg/dL in the previously abated group. Baseline blood lead concentrations in the modern urban group were statistically lower than baseline levels in the other four groups. Further, children's blood lead concentrations were correlated significantly (r=.28 to .64) with measures of lead in dust from six types of interior house surfaces and exterior entryways.

Houses in all study groups were generally similar in terms of characteristics that might be expected to influence patterns of dust movement into and within a house, including overall size, number of windows, house type and design, condition, degree of setback from the street, and the presence of porches and yards. Statistically significant differences were not found in demographic characteristics, children's blood lead concentrations, and dust lead concentrations between R&M groups at baseline. However, baseline dust lead loadings tended to be highest in R&M III houses (vacant at baseline), lowest in R&M I houses (occupied at baseline), and intermediate in R&M II houses (a mix of vacant and occupied houses). Baseline weighted average lead loadings within an entire house were 16,600 $\mu g/ft^2$ in R&M I houses, 24,000 $\mu g/ft^2$ in R&M II houses, and 47,500 $\mu g/ft^2$ in R&M III houses, compared to 83 $\mu g/ft^2$ in the modern urban houses. Similar weighted average measures of baseline dust lead concentrations were nearly two orders of magnitude higher in R&M houses (19,000 μg/g in level I; 14,400 μg/g in level II; and 17,500 μg/g in level III) than in modern urban houses (235 μg/g). Previously abated houses had intermediate dust lead concentrations of 2,400 μg/g and lead loadings of 900 $\mu g/ft^2$. The baseline data collection campaign in the previously abated houses represents a point in time two years to four years post-abatement. In these houses, the geometric mean lead loadings for floors and window sills, but not window wells, were found to be at or below the interim clearance standards set by the U.S. Department of Housing and Urban Development (HUD)[4] and the clearance standards guidance published by the U.S. Environmental Protection Agency (EPA)[5].

Table 1: Comparison of Elements of Repair & Maintenance Levels I - III

ELEMENT OF INTERVENTION	R & M LEVEL I	R & M LEVEL II	R & M LEVEL III
TESTING	Test for the presence of lead-based paint (LBP) on interior and exterior surfaces. Use results to develop the R&M Plan.	Test for the presence of lead-based paint (LBP) on interior and exterior surfaces. Use results to develop the R&M Plan.	Test for the presence of lead- based paint (LBP) on interior and exterior surfaces. Use results to develop the R&M Plan.
FLOOR TREATMENTS	Pace textured walk-off mat at main entryway.	If LBP, provide floor covering. If not LBP, seal floors to make smooth and cleanable surfaces. Place textured walk-off mat at main entryway. In occupied units, treat floors to extent possible.	If LBP, provide floor covering. If not LBP, make floors smooth and cleanable with combination of coverings and sealants. Place textured walk-off mats at main entryway.
TRIM COMPONENT TREATMENTS	Remove loose and peeling LBP on interior surfaces, and on exterior surfaces to limit of budget. Repaint treated components.	Remove loose and peeling LBP on interior surfaces, and on exterior surfaces to limit of budget. Repaint treated components. If not LBP, make interior surfaces smooth and cleanable.	Seal, encapsulate, or enclose LBP on interior and exterior surfaces. If not LBP, make interior surfaces smooth and cleanable.
STAIRWAY TREATMENTS	None	If LBP present, encapsulate treads and risers, at minimum. If not LBP, make smooth and cleanable.	If LBP present, enclose treads and risers using durable materials. If not LBP, make smooth and cleanable.
WINDOW TREATMENTS	Install aluminum cap on window wells. Prepare and repaint all exterior window trim. Repaint interior stool with non-flat paint.	If LBP present, treat in-place to reduce friction. Stabilize paint on exterior trim. Install aluminum caps on wells. Repaint interior sill with non-flat paint. If not LBP, make smooth and cleanable.	If LBP present, replace window and abate exterior window trim by enclosing with aluminum coverings. If not LBP, make smooth and cleanable.
DOOR TREATMENTS	Same as TRIM COMPONENT TREATMENTS.	If LBP, rework interior and exterior doors to reduce friction. Remove peeling LBP paint and stabilize exterior door trim. Repaint treated surfaces. If not LBP, make smooth and cleanable.	If LBP, rework interior and exterior doors to reduce friction or replace. Remove peeling paint. If not LBP, make smooth and cleanable. Enclose LBP on exterior door trim with aluminum coverings.

Table 1: Comparison of Elements of Repair and Maintenance Levels I - III
(Continued)

ELEMENT OF INTERVENTION	R & M LEVEL I	R & M LEVEL II	R & M LEVEL III
WALL TREATMENTS	Same as TRIM COMPONENT TREATMENTS.	If LBP and < 25% of component is damaged, repair damaged area and seal component, at a minimum. If LBP and >25% of component is damaged, repair damaged area and treat by use of flexible encapsulant or rigid enclosure.	If LBP and < 25% of component is damaged, repair damaged area and encapsulate, at a minimum. If LBP and >25% of component is damaged, then treat by use of flexible encapsulant or rigid enclosure.
FINAL CLEAN-UP	HEPA vacuum all horizontal surfaces and window components (ceilings excluded). Then wet clean horizontal surfaces.	HEPA vacuum all surfaces excluding ceilings. Then wet clean horizontal surfaces.	HEPA vacuum all surfaces excluding ceilings. Then wet clean horizontal surfaces.
CLEANING KITS	Provide cleaning kits to occupants for use after R&M work is completed.	Provide cleaning kits to occupants for use after R&M work is completed.	Provide cleaning kits to occupants for use after R&M work is completed.
EDUCATION	Provide educational materials about lead poisoning to occupants.	Provide educational materials about lead poisoning to occupants.	Provide educational materials about lead poisoning to occupants.

1.1 Report Objectives

The primary objectives of this report are to:

- Describe lead loadings and concentrations in settled house dust for the three levels of R&M intervention at baseline and across the four data collection campaigns conducted during the first year of follow-up, i.e., immediate post-intervention, and two months, six months, and 12 months post-intervention.

- Describe changes in lead loadings and concentrations in settled dust between baseline and the 12-month campaign for the control houses which consist of modern urban houses built after 1979 and houses that received comprehensive abatement in the past.

- Apply the study's statistical models for longitudinal data analysis to the dust lead and blood lead data.

- Report on compliance with laboratory data quality objectives.

1.2 Purpose of the R&M Study

Past studies have documented the short-term (2 months to 6 months) and longer-term (12 months or longer) effectiveness of comprehensive approaches to residential lead paint abatement intended to attain long-term control of lead paint hazards.[6,7] In recent years, there has been growing interest in the concept of interim measures to temporarily control the extensive problem of lead-based paint hazards in housing in a cost-effective manner. Title X of the Housing and Community Development Act of 1992 (P.L. 102-550) defined interim controls as " a 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 of management and resident education programs." More recently, the June 1995 HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* operationalized the concept by compiling information on interim control practices.[4] Many believe these measures will benefit large numbers of current and future occupants of housing with lead-based paint hazards. However, little is known about the short- and long-term effectiveness of this approach.[8]

The R&M study is designed to document the short- and long-term effectiveness of a range of housing interventions, including interim control measures, designed to reduce children's exposure to lead in paint and in settled dust. This research is important because house dust and residential paints containing lead have been identified as major sources of exposure in U.S. children,[9-15] Primarily via the hand-to-mouth route of ingestion:[9, 15-18] Families with children under seven years of age occupy approximately 10 million of the 57 million privately owned and occupied U.S. housing units that are estimated to contain some lead-based paint.[19] Children living in the nearly 4 million houses with deteriorating paint and elevated dust lead levels are at highest risk of exposure.[19] Given the extent of the problem and the high costs of remediation by comprehensive abatement practices, the preventive R&M approach may provide a practical means of reducing exposure for future generations of U.S. children who will continue to occupy housing that contains lead-based paint. This study represents the first systematic examination of the R&M approach.

The goal of the study is to contribute to the existing scientific bases needed to develop a standard of care for lead-painted houses through the analysis of environmental and biological data from a longitudinal intervention study. Specific study objectives are as follows:

- Measure the short- and longer-term changes in the lead concentration and lead loading of settled house dust and changes in children's blood lead concentrations associated with the three levels of R&M intervention (I-III), as compared to houses that had undergone previous comprehensive abatement and to a group of modern urban houses presumed free of lead-based paint based on their post-1979 year of construction.

- Characterize the nature of the relationship between lead in children's blood and settled house dust.

- Evaluate and compare methodologies for the collection and analysis of lead in residential dusts, including wipe and cyclone methods. This objective has been addressed in previous reports.[20-22]

1.3 Peer Review

All four of the independent external reviewers recommended publishing the report after minor revisions. A number of the reviewers' comments were related to the study design and the interpretation and generalizability of study findings, potential confounders, and policy implications. In light of this, the report places additional emphasis on the nature of the intervention (R&M work plus feedback of information to families), its relation to generalizability of the findings, and the limited generalizability of study data on R&M costs and lead concentrations of soil and tap water. Soil and water were tested for lead to account for these sources in the analysis of the longitudinal dust lead and blood lead data; the study was not intended to answer other scientific questions about these sources. Further, we plan to request EPA funding to test for lead-based paint in the modern urban control houses to validate our assumption that they are free of lead-based paints. If testing is done, paint lead data will be included in subsequent reports. Otherwise, a discussion of this assumption will be added to the next study report. Lastly, we agree that additional data on residential dust lead loadings and dust lead concentrations in communities across the country would increase the utility of study findings and better inform the policy making process.

To aid the reader in the interpretation of study data, a description of the comprehensive abatements performed in the previously abated control houses was added to Section 4.2, and data on the distributions of baseline blood lead concentrations were included in Appendix B. Further, it is noted that the variances of baseline blood lead concentrations across the three R&M groups were essentially the same and that housing characteristics such as degree of setback from the street and the presence of a porch were not significant additions to the statistical models for dust lead loadings and concentrations in the presence of season, group and campaign. Section 2.0 now explains that the difference in average dust lead loadings between the R&M III and the previously abated houses may be due to differences in time since intervention. The report also clarifies the following points in response to reviewers' comments: (a) the study can not determine effect of R&M I on the blood lead concentrations of children with initial blood lead concentrations ≥20 μg/dL due to limited data, and (b) demographic data are not available to compare study households to the small proportion of households which did not express an interest in participating. More than 90 percent of households identified as potentially eligible for the study indicated an interest in participating.

A reviewer questioned whether the study could determine the effectiveness of R&M interventions in preventing childhood lead exposure, as measured by blood lead concentrations, given the ages of the children and the extent of their lead-exposure at baseline. The study can determine in several ways whether the R&M interventions are effective in preventing lead exposure, as measured by children's blood lead concentrations. First, it can show whether or not their blood lead concentrations reach levels that trigger medical management (≥15-20 μg/dL according to the CDC guidelines) during the post-intervention period of follow-up. Second, it can show whether R&M interventions are associated with acute increases in blood lead concentration during the immediate post-intervention phase; this is important because past studies have documented acute increases in children's blood lead following improper lead-paint abatement work. Third, to assess the potential for primary prevention of lead poisoning, the study design includes the enrollment of newborns during the follow-up phase, once they reach the age of six months. Children born into study households were not included in this report due to small numbers; however, a separate analysis of their blood lead data is planned for the report on the second year of follow-up. Also with regard to primary prevention, this study shows that the modern urban control houses are associated with children's blood lead concentrations below the CDC's level of concern (10 μg/dL).

One reviewer commented that the performance of R&M interventions in vacant and occupied houses was likely to have an effect on whether there were significant reductions in dust lead loading and concentrations in R&M I houses (occupied at time of intervention) as compared with R&M III houses (vacant at the time of intervention). This point would be of particular importance if this were a study of changes in dust lead loadings and concentrations immediately following R&M interventions. However, in this report data were analyzed in terms of dust lead loadings and concentrations during the first year of follow-up, both within and between groups, and not in terms of absolute change in dust lead levels immediately following intervention. Moreover, in the report on pre-intervention findings, the baseline data were analyzed by treatment group rather than by occupancy status because our primary interest was to assess the comparability of groups on measures of dust lead and blood lead at baseline and then to compare dust lead loadings and concentrations and blood lead concentrations over time within and between groups. Further, the group variable accounted for more of the variability in the dust lead data than the status variable (occupied/vacant) in our statistical analysis.

On a related point, a reviewer pointed out that R&M II interventions were performed in both vacant and occupied units and asked whether vacancy influenced the amount, quality, or cost-effectiveness of the R&M activities. Vacancy did influence the extent to which floors were treated in R&M II houses and the need for precautions to protect furnishings and other belongings. As noted in the report, in the case of occupied houses, family members were out of the house while work was in progress and floors were treated to the extent feasible, given the presence of furnishings and the drying times of the sealants selected for use. In vacant R&M II houses, all floors were available for treatment and there was no need to take precautions to protect furnishings and personal belongings.

One reviewer noted that the finding of some sporadic reaccumulation of lead dust loading to pre-interventions levels at some sites in R&M houses highlights the importance of counseling families to conduct regular, targeted lead cleaning in their homes, even after deleading. The potential for reaccumulation of lead in dust was one reason why this study was designed to include feedback of information on household dust lead loadings to participating families. Additionally, HUD guidelines recognize the need for ongoing inspection and maintenance of houses that have received interim control interventions. Further, it is important to emphasize that the longevity of the three R&M interventions under investigation is unknown; sustained reductions were found in dust lead loadings during the first year of follow-up in each of the three intervention groups as explained below.

2.0 SUMMARY AND DISCUSSION OF FINDINGS

During the first year of follow-up, this study met objectives related to enrollment, laboratory performance, data quality and data completeness (section 3.0). The latter is attributable to the study families' willingness to cooperate with the blood lead testing and the environmental sampling components of the study. This, in turn, is a reflection of the good rapport established between study staff and participating households. During the first year of follow-up, 21 (20 percent) of the 107 original families moved from study houses. In all but three cases, the house was subsequently reoccupied and the new family was enrolled in the study. This assured that, at a minimum, the house remained in the study. Most of the new families also had eligible children who were enrolled in the blood lead testing component of the study.

All families were informed by letter of the results of the dust lead and blood lead tests from each campaign. Results of dust tests were provided on a qualitative basis with recommendations for housekeeping priorities to address areas with high dust lead loadings. For this reason, it is important to emphasize that the study intervention consisted of a combination of R&M work and the provision of information to families on a periodic basis. The nature of the intervention limits the degree to which study findings can be generalized to houses which will receive R&M interventions, but no periodic monitoring of dust lead levels and/or feedback of results to families. It is also important to note that the costs of the interventions in this project may not be generalizable to other settings and time periods due to potential differences in labor and material costs and overhead rates.

This section summarizes and discusses the main findings, including those based on the fitting of the study's statistical models for longitudinal data analysis (section 6.3) to the dust lead and blood lead data. The longitudinal models enabled investigation of lead levels in house dust and in children's blood across time within study groups and comparisons between groups during the first year of follow-up, accounting for age, season, and other potential covariates. These models also address statistical issues associated with having multiple measurements per house and repeated measures over time.

Dust Lead In R&M Houses

All three levels of R&M interventions under investigation (section 4.2) were associated with statistically significant reductions in both interior dust lead loadings and dust loadings that were sustained below pre-intervention levels during the first year of follow-up. Moreover, none of the interventions in individual houses failed, that is, all or most of the dust samples showed lead loadings at, or below, pre-intervention levels during the first year of follow-up. Reaccumulation of dust and dust lead loadings in all three R&M groups was the greatest during the first two month post-intervention, while there was relatively little reaccumulation between two months and 12 months post-intervention (Figures 23 and 24). This early reaccumulation was most evident in R&M II and R&M III houses and may be due in part to the possible importation of dust and lead into the house during move-in by study families. Half of the R&M II houses, all of the R&M III houses, and none of the R&M I houses were vacant at the time of intervention. Vacancy is also believed to account for the finding of highest baseline dust lead loadings in R&M III houses (vacant at baseline) and lowest baseline lead loadings in R&M I houses (occupied at baseline).

As expected, the dust lead loadings, lead concentrations, and dust loadings during the post-intervention period of follow-up were related to the intensity of the intervention. Environmental samples collected immediately following intervention and at two, six and 12 months post-intervention consistently showed dust lead loadings, lead concentrations, and dust loadings to be lowest in R&M III houses, intermediate in R&M II houses, and highest in R&M I houses. Statistically significant differences were found between R&M groups on these three dust measures throughout the first year of follow-up. Weighted average measures of dust lead levels on floors, window sills, and window wells in an entire house indicated that the relative differences in exposure between groups were large. For example, at twelve months post-intervention, weighted average dust lead loading estimates were 21-fold higher in R&M I houses than in R&M III houses, and 4-fold higher in R&M II houses than in R&M III houses. In R&M I houses, the 12-month geometric mean dust lead loading for floors in rooms with windows was 94 $\mu g/ft^2$, for window sills it was 470 $\mu g/ft^2$, and for window wells it was 16,698 $\mu g/ft^2$. In R&M II houses, the 12-month geometric mean dust lead loading for floors in rooms with windows was 76 $\mu g/ft^2$, for window sills it was 237 $\mu g/ft^2$, and for window wells it was 2,587 $\mu g/ft^2$. Finally, in R&M III houses, the 12-month geometric mean dust lead loading for floors in rooms with windows was 50 $\mu g/ft^2$, for window sills it was 29 $\mu g/ft^2$, and for window wells it was 220 $\mu g/ft^2$.[a] Differences in lead loadings between groups are attributable mainly to differences in lead concentrations between groups and secondarily attributable to differences in dust loadings (Figure 22).

Dust lead concentrations were found to be statistically significantly reduced following intervention in R&M II and R&M III houses, but not in R&M I houses. Significant differences in dust lead concentrations between R&M groups were anticipated based on differences between the three levels of intervention. By design, R&M III interventions, and to a lesser extent R&M II interventions, directly addressed lead-based paint, a source of high lead concentrations in house dust. For example, R&M III interventions typically involved the replacement of lead-painted windows and the use of durable aluminum coverings to enclose lead paint on exterior components of windows and doorways. In R&M II interventions, window friction surfaces were treated to reduce the abrasion of lead paint, but windows generally were not replaced. In contrast, R&M I interventions directly addressed paint sources only to the extent that deteriorating paint on interior and exterior surfaces was stabilized and window wells were capped with aluminum coverings. Sustained reductions in lead concentrations in R&M II and R&M III houses, and less frequent observations of paint chips on sampled window surfaces during follow-up, indicate that these interventions contributed to the control of paint as a source of high lead concentrations in house dust for a one-year period. A reduced rate of lead input into dust from paint may explain in part the downward trend in dust lead concentrations in R&M II houses two months following intervention even in the presence of rising dust loadings. A sharp rise in dust lead concentrations in future data collection campaigns would likely signal the presence of lead paint hazards and the need for further remediation.

The patterns observed in dust loadings and dust lead concentrations between R&M groups also may be related to the degree to which the surfaces in the three levels of intervention were made smooth and easily cleanable. For example, in R&M III houses, floors were covered or sealed to make them smooth and easily cleanable. Floors in R&M II houses were sealed (to the degree possible in the subset of houses occupied at the time of intervention), while floors in R&M I houses were neither sealed nor covered. Also, the window wells in the houses in all three R&M groups were covered in some manner. The provision of smooth and easily cleanable surfaces has been shown to be an important element of effective residential lead paint abatement.[6,7] In this study, surface conditions would have influenced the effectiveness of the post-R&M cleanup by

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[a] It should be noted that the cyclone device used to collect dust in this study has been shown to produce higher estimates of dust lead loadings compared to wipes across a range of surface types and conditions. However, the cyclone device tends to yield lower estimates of dust lead loadings than wipes on smooth surfaces with low lead loadings ($< \sim 100$ $\mu g/ft^2$).[21]

contractors and housekeeping by study families. Based on field data recorded at the time of sampling, window well surfaces in the three groups of intervention houses were generally smoother and less deteriorated one year post-intervention compared to the pre-intervention baseline.

Dust Lead In Control Houses

The modern urban and previously abated control houses were characterized by a relative stability of dust lead loadings, lead concentrations, and dust loadings over time (Figure 24). No statistically significant differences in the three dust measures were found within in these two groups during the first year of follow-up. Downward but nonstatistically significant trends were noted in lead loadings and dust loadings across time for both groups of houses. These trends may be related, in part, to families becoming more aware of the importance of lead dust control as a result of study participation and to the fact that dust was repeatedly removed from household surfaces by the sampling process.

The modern urban control houses are rowhouses located in clusters of houses built after 1979 and presumably free of lead-based paint because of the year of construction.[48] It is expected that this type of housing reflects the lowest residential and ambient lead levels in the urban environment. The consistently low overall interior dust lead concentrations (geometric mean ≤310 μg/g (ppm), equivalent to ≤0.03%) and low soil lead concentrations (geometric mean ≤75 μg/g) support the presumption that these houses are free of lead-based paints. As noted previously, the investigators are seeking EPA funding to test the paint in the modern urban control houses to determine directly if the paint contains lead additives. This group of houses had significantly lower dust lead loadings and lead concentrations compared to each of the other study groups at baseline and throughout the first year of follow-up. At one year, weighted average lead loadings in modern urban houses were three times lower than in R&M III houses. The geometric mean dust lead loading for floors in these houses was 8 μg/ft^2, for window sills it was 9 μg/ft^2, and for window wells it was 208 μg/ft^2 compared to previously abated houses where the geometric mean dust lead loading for floors was 77 μg/ft^2, for window sills it was 75 μg/ft^2, and for window wells it was 1,164 μg/ft^2.

The previously abated control houses had geometric mean lead loadings at the six-month and 12-month campaigns that tended to be between the levels found in R&M II and R&M III houses. These findings may be related to differences in time since intervention between R&M groups and this control group. The 12-month campaign occurred three years to five years post-abatement in the previously abated control houses. Further, average dust lead concentrations in R&M II and R&M III houses were not significantly different from those in previously abated houses at six and 12 months. This is consistent with the fact that none of these interventions, including the comprehensive abatements, involved the complete removal of all lead-based paint from a home. As illustrated by the case in which a child's blood lead concentration rose to 53 μg/dL during follow-up, the previously abated control houses were comprehensively, but not fully, abated of lead paint. In these houses, some interior (in this case basement) surfaces that had not been treated due to resource limitations, and some painted exterior surfaces that had been stabilized as part of the original abatement were found to be in deteriorated condition during the R&M study sampling campaigns. These problems combined with deteriorating exterior paint on neighboring houses, were likely sources of this child's exposure. This case points to the need for ongoing inspection and maintenance of houses, particularly those houses that receive less intensive interventions.

It should be emphasized that the three R&M interventions being investigated in this study are interim control or partial abatement approaches to reducing lead-based paint hazards in housing. As such, they are not expected to be as long-lasting as comprehensive abatement, and documentation of the longevity of the R&M interventions is, therefore, a major study objective. To date, dust lead loadings at sporadic sites in individual study houses (particularly in R&M I houses) have reaccumulated to levels close to pre-intervention levels. However, during the first year of follow-up, none of the R&M interventions in houses exhibited widespread failure. All or most of the interior dust lead loading measurements in R&M houses were at or below pre-intervention levels during the first year of follow-up. If failures do occur, contingency funds will be used to perform additional remediation work.

Lead In Drip-Line Soil And Tap Water

Soil and water samples were tested in order to take these sources into account in the analysis of the longitudinal dust lead and blood lead data. Soil lead data were limited due to the absence of drip-line soil at most study houses, except for at modern urban houses. Geometric mean soil lead concentrations at baseline and six months ranged from 700-730 μg/g in R&M I and R&M II houses and were an order of magnitude higher than the soil lead levels measured at the modern urban houses over time (geometric means of 63-73 μg/g). The low soil lead concentrations found at the modern urban houses are consistent with the possible use of replacement sod or soil at the time of construction of these houses (Table 17). Tap water was found to have low concentrations of lead. Geometric mean water lead concentrations across groups were $\leq$4 μg/L (ppb) at the initial and six month campaigns, and only a small number of readings exceeded the EPA drinking water standard of 15 μg/L (Table 18). The combination of low water lead concentrations and the absence of a significant correlation between children's blood lead concentrations and water lead concentrations indicates that water was not likely to have been an important source of lead exposure in study children. Beyond this, no major conclusions were drawn with regard to these sources due to the limited generalizability of these water and soil data.

Blood Lead

The majority of U.S. children with elevated blood lead concentrations defined by the U.S. CDC as $\geq$10 μg/dL have lead concentrations in the range of 10-20 μg/dL.[23] Little is known, however, about blood lead changes associated with lead paint hazard reduction interventions in the homes of children with low-to-moderate blood lead concentrations.[8,24] In this study, the unadjusted geometric mean blood lead concentrations (PbB) at baseline were 10 μg/dL for R&M I children, 14 μg/dL for R&M II children, and 14 μg/dL for R&M III children, and 13 μg/dL for children in the previously abated houses and 5μg/dL for children in the modern urban houses. At the end of the first year of follow-up, the unadjusted geometric mean blood lead concentrations were lower for each group: 8 μg/dL for R&M I children, 11 μg/dL for R&M II children, and 12 μg/dL for R&M III children, and 12 μg/dL for children in the previously abated houses and 3 μg/dL for children in the modern urban houses (Table 16). Mean ages at the end of the first year of follow-up ranged from 39 months to 44 months across groups.[b]

One of the study's longitudinal data analysis models allowed for comparisons of blood lead concentrations within and between groups, and for control of age, season and other potential covariates. This comparison model was fit separately for children with blood lead concentrations $<20\mu$g/dL and $\geq 20\mu$g/dL. According to CDC guidelines, children with blood lead concentrations $\geq 20\mu$g/dL should be referred for medical evaluation and management.[10] Children born into study houses were not included in this report due to the small number of children involved.

In children with initial blood lead concentrations (PbB) <20 μg/dL, no statistically significant changes in blood lead concentration were found <u>within</u> any of the five study groups during the first year of follow-up, controlling for age and season. Further, no significant differences in blood lead concentrations were found <u>between</u> R&M groups during the first year of follow-up, again controlling for covariates. Children in the modern urban control group had statistically significantly lower blood lead concentrations than children in the other four groups. This was the only statistically significant blood lead finding among study children with initial blood lead concentrations <20 μg/dL. The blood lead concentrations of children in the modern urban group were all less than or equal to the CDC's blood lead level of concern (10 μg/dL) during the first year of follow-up.

The absence of an increase in blood lead concentration at two months post-intervention is noteworthy because past studies have attributed short-term rises in children's blood lead concentrations to improper abatement practices.[24-26] Precautions taken in R&M houses included having children out of the house while R&M work was in progress and the use of work practices to minimize, contain, and remove lead-contaminated dust. Further, one could hypothesize that, accounting for age, the R&M interventions prevented increases in blood lead concentrations during the entire first year of follow-up that study children might have experienced otherwise in the absence of the R&M interventions. For ethical reasons, the study design did not include a non-

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[b] The geometric mean blood lead concentration (PbB) for children in the modern urban group was slightly above the geometric mean of 2.7 µg/dL reported for U.S. children aged 12 months to 60 months but very similar to that estimated for all non-Hispanic black children in this age range, 4.3 µg/dL.[1] The unadjusted geometric mean PbB in each of the other four study groups was similar to, or higher than, the estimated geometric mean PbB value of 9.7 µg/dL previously reported for U.S. non-Hispanic black children for low-income families living in central cities (populations >1 million, 1988-1991).[23]

intervention control group to test this hypothesis.

As anticipated, nearly all children with baseline blood lead concentrations ≥20μg/dL were in the R&M II and R&M III groups because the policy of one of the collaborating housing organizations was to rent its improved properties to families with lead-poisoned children. Children across all groups with initial blood lead concentration ≥20μg/dL (n=19) had a statistically significant reduction in blood lead concentration (in most cases to levels <20μg/dL) during the first year of follow-up, controlling for age and season (Figures 14-18). Due to small numbers, the effect of R&M I intervention on the blood lead concentrations of children with baseline blood lead concentrations ≥20μg/dL cannot be assessed in this study.

Relationship Between Blood Lead And Dust Lead

At the end of the first year of follow-up, statistically significant correlations, ranging from .28 to .44, were found between children's blood lead concentrations and dust lead loadings (both on the log scale) for various surface types (Tables 22 and 23). These low-to-moderate magnitude correlations are consistent with those reported in the literature.[14,15] A statistical model was used to assess the relationship between blood lead concentration and dust lead loadings and concentrations, controlling for covariates. Using data from all five study groups in the longitudinal data analysis, blood lead concentration was found to be significantly related to a linear combination of floor, window sill, and window well dust lead loadings and to a similar composite measure of dust lead concentrations, after controlling for age and season. Gender and hand-to-mouth activity were not found to be consistently significant contributors to the model in this study. The latter may be attributed to the more-or-less truncated blood lead concentration distribution and the aging of study children. Further, a statistically significant relationship was not found between dust lead loadings and concentrations and blood lead when the statistical model was fitted to blood lead concentration data from just the three R&M groups. This was likely due to the narrower range of post-intervention dust lead loadings and concentrations, compared with pre-intervention dust lead loadings and concentrations, exacerbated by the absence of the low-lead modern urban houses and children living in these types of houses from the analysis. Other studies, including a recent study in Rochester,[14] have found a statistically significant relationship between children's blood lead concentrations and lead in settled dust in their homes.

Seasonal change in children's blood lead concentration was estimated to be +1.2 μg/dL in summer relative to the other seasons, controlling for age, campaign and dust lead loading and concentration. Other studies have reported seasonal trends in children's blood lead concentrations for different years and populations that vary in the estimated magnitude of the seasonal difference but generally were higher than that reported here.[27-29]

Considerations In The Interpretation Of Blood Lead Findings

Multiple factors can theoretically mediate a child's blood lead concentration response to an intervention. These factors may include cumulative body lead burden, age, degree of hand-to-mouth activity, ambient lead levels, and neighborhood housing characteristics.

Housing history data, combined with the baseline blood lead concentration data, suggest that children in the modern urban houses had lower body lead burdens at the time of enrollment than did children in the other four study groups. Most children in the modern urban group had lived in the same low-lead house since birth, and all of them had baseline blood lead concentrations less than or equal to the CDC's blood level of concern (10 μg/dL). By contrast, it is likely that the children in the R&M and previously abated houses had spent most or all of their lives prior to enrollment in low-income rental housing and thus were at risk of high exposure to lead in dust and paint due to poor housing conditions. On average, baseline blood lead concentrations in these four groups of children were two to three times higher than those of children in the modern urban group. Body lead burdens could have mediated children's blood lead concentration responses to the R&M interventions because blood lead reflects a mixture of recent exposure and lead that the body has stored.

Most (~70 percent) of the lead in children is stored in their bones,[30] and the half-life of lead in human adult cortical bone is estimated to be 20 years.[31] This skeletal lead can be an ongoing internal source of lead measured in blood even after external exposure and children's lead ingestion are reduced following lead remediation interventions. This was the case in an earlier study of children with much higher blood lead concentrations (geometric mean=63 μg/dL) who received inpatient chelation therapy and were monitored for several years following discharge to "lead-free" public housing and abated houses.[32] Because the bone lead concentrations of R&M study children are unknown and the kinetics of lead mobilization from children's bones is not well understood, it is not possible to estimate the magnitude and duration of bone lead's contribution to children's blood lead concentrations measured in the post-intervention phase of this study. For this reason, additional time beyond 12 months post-intervention may be needed to measure significant blood lead changes in R&M children. The newborns who are being added to the study over time during the period of follow-up are of particular interest because they are likely to have had minimal exposure to lead prior to enrollment (age six months) and therefore can be followed to assess the potential for primary prevention of lead poisoning.

Additionally, ambient lead levels in study neighborhoods may have mediated the children's blood lead responses to intervention and contributed to blood lead differences between the modern urban group and the other four groups. By design, the modern urban houses were all located in housing clusters built after 1979 and are presumably free of lead-based paint. The low lead concentrations found in interior dust, exterior dust, and soil support the notion that these control houses were associated with low ambient lead levels. The children in this group were, therefore, at low risk of exposure to lead in paint and in the general environment, compared to children living in the R&M houses and previously abated houses which are located in low-income lead-contaminated neighborhoods. Such neighborhoods often have housing in poor condition and in close proximity to abandoned and boarded houses.

Because hand-to-mouth activity is recognized as a major entry route for lead into preschool children,[16-18] age and frequency of hand-to-mouth activity are other potential factors mediating children's blood lead response to an intervention. At the 12-month campaign, most study children were 36 months to 48 months of age, a range in which the frequency of mouthing behavior is likely to be less than in infants and young toddlers. This potential reduction in hand-to-mouth activity could account, in part, for the lack of statistically significant changes in blood lead concentration within and between R&M groups in children with baseline blood lead concentration <20 μg/dL, despite the differences in dust lead exposure between and within groups over time.

The children with blood lead concentrations ≥ 20 μg/dL may have had higher blood lead concentrations due to more frequent hand-to-mouth activity. It also is possible they may have had a relatively greater contribution to their blood lead from current exposure rather than from bone lead, compared to children with blood lead concentrations <20 μg/dL. Therefore, their blood lead concentrations may have been more responsive to the reduction in lead exposure associated with the R&M interventions than children with lower baseline blood lead concentrations.

The reader is referred to section 7.0 for a more detailed presentation of these and other findings during the first year of follow-up.

3.0 QUALITY ASSURANCE

3.1 System Audit

Laboratory and field activities have been subjected to regular review to assure conformance with procedures proscribed in the Quality Assurance Project Plan.[2] This ongoing audit has focused on the sampling and analytical procedures used, their documentation, the training of field and laboratory personnel, and the adequacy of related facilities and equipment. Reports have been generated and forwarded to the project officer annually. Inadequacies noted in early reports have been subsequently corrected. Only minor problems, not directly related to data quality, were noted during the first year of follow-up.

3.2 Data Audit

To verify the accuracy of the data used in this report, the quality control officer conducted a stratified random audit of 5 percent of the field and laboratory data generated during the first two years of this study. Prior to the audits, laboratory and data staff had completed independent checks of the data. The audit procedure involved the verification of information in the final data base against the original field and laboratory data. Samples to be audited were selected by computer using random number sequences. Sampling was stratified to ensure that samples were randomly selected to represent every analytical batch. Probably as a result of the extensive quality control effort prior to the audits by the quality control officer, the audits did not identify any errors.

3.3 Performance Audit

In order to assure that the sampling and analytical protocols employed in the R&M study yielded data of sufficient quality, a number of different types of quality control samples were included in the study design. These samples were designed to control and assess data quality in each phase of the data collection and analysis process, which were potentially subject to random and/or systematic error. Blank samples, including field blanks and method blanks, were included to assess procedural contamination by lead. Recovery samples, including standard reference materials, spiked samples, and calibration verification samples, were included to indicate the accuracy of analyses. Duplicate samples were used to indicate precision of analyses. Standard control charts were generated quarterly showing percent recovery of a standard reference material, percent recovery of spiked samples, spike/spike duplicate precision, initial calibration values, continuing calibration values, percent recovery of continuing calibration values, and drift of continuing calibration values within a run. Separate control charts were generated for each combination of sample matrix and analytical instrument used. Of the more than 6,000 quality control samples included in these analyses, the control limit ($\pm$30 percent) was rarely exceeded for any quality control parameter. Data on field and method blanks also have been reviewed on a periodic basis as part of the performance audit.

In addition to these internal quality control efforts, the Kennedy Krieger Research Institute (KKRI) Trace Metals Laboratory has participated in external quality control programs for environmental lead samples and blood lead concentrations as a part of the R&M study. Beginning in September 1993, the laboratory participated in the Environmental Lead Proficiency Analytical Testing (ELPAT) program for environmental samples. This program is administered through the National Lead Laboratory Accreditation Program and is sponsored in part by EPA Office of Pollution Prevention and Toxics. Blind samples are analyzed quarterly; the KKRI Trace Metals Laboratory has been rated as "proficient" for the evaluation of lead in paint chips, soil, and dust wipes since joining the program. The Trace Metals Laboratory also participates in the Health Resources and Services Administration/Wisconsin Blood Lead Proficiency Testing Program. Three blind blood samples are analyzed every month as a part of this program. Since beginning this analysis in 1993 the KKRI laboratory has achieved a 100 percent accuracy rating for Graphite Furnace Atomic Absorption Spectroscopy (GFAA) analysis of blood lead for all rounds in which the laboratory participated.

Statistical Analyses of QC Data

Because of the overlapping nature of the sampling campaigns in this longitudinal study, samples from several campaigns are generated and analyzed concurrently. Consequently, there is no unique set of quality control data that can be attributed to any particular sampling campaign or set of campaigns. As a result, the quality control data reported here represent all data submitted as a part of quarterly reports through Oct. 25, 1996. These data include all of the samples from the initial sampling campaign through the 12-month campaign, plus varying numbers of samples from subsequent campaigns. Statistical analyses of the quality control samples are included in Tables 2 through 4. With the exception of soil samples, the percent recovery of standard reference material and the percent recovery of spike and spike duplicates all fell within a tolerance interval of 70 percent to 130 percent. Precision was very high, with generally less than a one percent difference between spike and spike duplicate samples. Percent recovery of initial and continuing calibration samples fell within a tolerance interval of 90 percent to 110 percent. Drift was limited to an average of less than two percent over a run. Field and method blanks showed extraneous lead contamination of the samples to be, on average, trivial. No evidence of systematic contamination was observed.

Additional quality control analyses were conducted on the environmental sampling data to assess potential bias resulting from sampling conducted by different field personnel. No statistically significant differences were found between the estimates of dust lead loadings, dust lead concentrations, and dust loadings based on samples collected by the various members of the field staff, after controlling for surface type and study group.

Table 2: Descriptive Statistics And Tolerance Limits For Percent Recovery For SRM And Spiked Samples And Percent Differences Between Spike And Spike Duplicate Samples

Sample Type	Type of Analysis	Number of Samples	Minimum (%)	Maximum (%)	Mean (%)	Standard Error	Lower Limit 95% Tolerance Interval (%)	Upper Limit 95% Tolerance Interval (%)
Standard Reference Material (SRM)	ICP-DV[a]	505	76.27	153.64	93.38	0.43	73.27	113.49
	GFAA-DV	425	79.34	119.59	92.96	0.32	79.13	106.78
	GFAA-S[a]	20	43.14	108.39	91.47	3.23	51.66	131.28
	GFAA-W[a]	73	50.99	129.18	98.16	1.85	61.98	134.33
Spike/Spike Duplicate	ICP-DV SPIKE	505	82.33	119.92	97.05	0.21	87.18	106.91
	ICP-DV SPIKE DUPLICATE	505	77.09	121.03	96.87	0.22	86.54	107.20
	ICP-DV PERCENT DIFFERENCE	505	-20.99	13.29	0.20	0.13	-0.05	0.44
	GFAA-DV SPIKE	427	80.00	118.00	98.12	0.31	84.71	111.52
	GFAA-DV SPIKE DUPLICATE	427	79.00	139.00	98.04	0.34	83.46	112.62
	GFAA-DV PERCENT DIFFERENCE	427	-36.09	29.31	0.12	0.24	-0.35	0.59
	GFAA-S SPIKE	20	-263.00	289.00	82.18	21.44	-181.8	346.11
	GFAA-S SPIKE DUPLICATE	20	35.00	142.00	92.16	5.78	20.94	163.37
	GFAA-S PERCENT DIFFERENCE	20	-25.89	47.01	-0.03	3.06	-6.44	6.37
	GFAA-W SPIKE	73	72.80	117.80	97.45	0.98	78.19	116.72
	GFAA-W SPIKE DUPLICATE	73	40.80	120.60	97.19	1.31	71.57	122.80
	GFAA-W PERCENT DIFFERENCE	73	-7.41	64.87	0.54	0.97	-1.40	2.48

[a] DV = cyclone dust, S = soil, W = water

Table 3: Descriptive Statistics And Tolerance Limits For Percent Recovery For ICV And CCV

Sample Type	Type of Analysis	Number of Samples	Minimum (%)	Maximum (%)	Mean (%)	Standard Error	Lower Limit 95% Tolerance Interval (%)	Upper Limit 95% Tolerance Interval (%)
Initial Calibration Verification (ICV)	ICP-DV[a]	287	93.08	109.98	100.50	0.18	93.97	107.04
	GFAA-DV	120	92.50	110.00	103.41	0.34	95.28	111.54
	GFAA-S[a]	34	93.50	109.00	102.57	0.60	93.89	111.25
	GFAA-W[a]	63	96.00	110.00	103.40	0.41	95.77	111.04
Continuing Calibration Verification (CCV)	ICP-DV % TRUE VALUE	1937	90.02	112.70	98.82	0.09	90.94	106.70
	ICP-DV % DRIFT	1937	-13.95	14.53	-1.68	0.10	-1.88	-1.49
	GFAA-DV % TRUE VALUE	476	90.50	112.50	102.80	0.20	93.82	111.77
	GFAA-DV % DRIFT	476	-12.15	11.46	-0.83	0.20	-1.22	-0.43
	GFAA-S % TRUE VALUE	77	89.00	109.00	101.14	0.58	89.47	112.81
	GFAA-S % DRIFT	77	-13.88	9.23	-1.09	0.54	-2.17	-0.01
	GFAA-W % TRUE VALUE	173	90.50	110.00	102.77	0.34	93.21	112.33
	GFAA-W % DRIFT	173	-12.80	11.86	-0.51	0.33	-1.17	0.14

[a] DV = cyclone dust, S = soil, W = water

Table 4: Descriptive Statistics For Field Blanks And Method Blanks

Sample Type	Type of Sample	Number of Samples	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	Standard Error
Field Blank	Dust[a]	796	0.06	621.00	8.67	1.39
	Soil	107	0.01	2.59	0.17	0.03
	Water	364	0.15	92.00	1.42	0.27
Method Blank	Dust	507	-152.00	549.00	7.81	1.83
	Soil	20	-0.40	14.00	2.55	0.86
	Water	73	-0.80	8.90	0.62	0.14

a Field blanks are analyzed by ICP or GFAA

4.0 STUDY DESIGN AND SAMPLE COLLECTION PROCEDURES

The R&M study targeted houses in low-income neighborhoods where children are at highest risk of lead-poisoning due to exposure to lead in dust and in deteriorating paint. It is important to emphasize that the R&M study was not designed as an intervention study in the homes of lead-poisoned children *per se,* although some study children did have blood lead elevations at baseline. Instead, the study started by identifying eligible intervention and control houses with eligible children. The eligibility criteria for children were based on age and other parameters, but not blood lead concentration (see section 4.4). It is also important to recognize that the study was not designed to assess the specific effects of the various elements of the interventions (e.g., provision of information to families) on the study outcomes. Instead, the study investigated the effectiveness of the R&M interventions as a whole. To assess the potential for primary prevention of lead poisoning, the study design included the enrollment of newborns once they reached the age of six months. The sections below provide an overview of the study design followed by descriptions of the R&M interventions, recruitment and enrollment procedures, selection criteria for houses and children, selected characteristics of the study houses, and sample collection procedures.

4.1 Overview Of Study Design

The R&M study has two main components and five groups of study houses. The first component is designed to obtain serial measurements of lead in the venous blood of children between the ages of six months and 60 months at enrollment. The study also obtained serial measurements of lead in house dust, exterior soil, and drinking water in three groups of 25 houses (a total of 75 houses), each being subjected to one of three levels of R&M intervention. The second component was designed to collect a comparable set of measurements in two groups of control houses. Table 5 summarizes the types of data planned for collection by study group and by campaign. Blood lead and dust lead measurements were planned in all R&M study houses at each campaign, except blood lead was not collected at the immediate post-intervention campaign. Measurements of lead in exterior soil and drinking water were made as part of a subset of all campaigns. The study questionnaire, designed to obtain information on demographics and covariates that could influence lead exposure in the home (*e.g.*, hobbies and child behavior), was administered at six month intervals starting at enrollment.

R&M intervention houses (vacant and occupied) were identified in collaboration with owners and operators of low-income rental properties as explained in section 4.3. Occupied houses that were eligible for R&M intervention were randomly assigned to receive either R&M I (low level intervention) or R&M II (intermediate level intervention). Vacant houses that were eligible for R&M intervention were randomly assigned to receive R&M II or R&M III (high level intervention). The R&M II intervention was designed to be performed in both occupied and vacant houses, and the randomization scheme was designed to ensure that equal numbers of houses (n=25) were assigned to each R&M intervention level. To allow for a better estimation of the post-intervention rate of re-accumulation of lead in dust and for periodic assessments of the need for further cleanups/repairs during the follow-up period, more frequent sampling campaigns were planned in the R&M groups during the first year of follow-up (Table 5).

Table 5: Data Collection Plan For Lead Paint Abatement And Repair & Maintenance Study

Study Group	Type of Data	Pre-Intervention /Enrollment Campaign	Post-Intervention Campaigns					
			Immediate	2 Months	6 Months	12 Months	18 Months	24 Months
R&M I	Blood	√	√	√	√	√	√	√
	Dust	√	√	√	√	√	√	√
	Soil	√	√		√		√	
	Water	√			√		√	
	Questionnaire	√			√	√	√	√
R&M II	Blood	√[a]	√[a]	√	√	√	√	√
	Dust	√	√	√	√	√	√	√
	Soil	√	√		√		√	
	Water	√[a]	√[a]		√		√	
	Questionnaire	√[a]	√[a]		√	√	√	√
R&M III	Blood		√[a]	√	√	√	√	√
	Dust	√	√	√	√	√	√	√
	Soil	√	√		√		√	
	Water		√[a]		√		√	
	Questionnaire		√[a]		√	√	√	√
Control Houses:	Blood	√			√	√	√	√
	Dust	√			√	√	√	√
Previously	Soil	√			√		√	
Abated and	Water	√			√		√	
Modern Urban	Questionnaire	√			√	√	√	√

Shading indicates data covered in this report

[a] Blood, questionnaire, and water samples were not collected in vacant houses until the family moved in following intervention.

The need for additional cleanups/repairs during the entire follow-up period will be determined by a comparison of the follow-up dust lead loadings and blood lead concentrations with their corresponding pre-intervention levels. Further cleanups/repairs will be performed when dust lead loadings at most interior sites in a house re-accumulate to levels that exceed pre-intervention levels. This assessment will exclude interior sites with low baseline dust lead loadings (*e.g.*, $<100\ \mu g/ft^2$) that remain low at follow-up, despite small increases in their lead loadings. In contrast, clean-up/repair will be considered for sites with high levels at baseline and at follow-up (*e.g.*, $>25{,}000\ \mu g/ft^2$) where the follow-up level approaches, but does not exceed, the corresponding baseline value.

The second component of the study is to obtain serial measurements of lead in venous blood of children six months through 60 months of age at enrollment, and in house dust, soil, and drinking water in two groups of control houses. The first control group consisted of 16 houses drawn from a group of houses that received comprehensive lead-paint abatement in demonstration projects in Baltimore between May 1988 and February 1991.[6,7] The second control group consisted of 16 modern urban houses built after 1979, which were presumably free of lead-based paint. The types and frequencies of measurement were the same in the two control groups (Table 5). The two years of follow-up planned for the previously abated control group will provide an opportunity to measure the effectiveness of comprehensive abatement four years to six years after abatement.

It should be noted that the sample sizes of the control groups were reduced from 25 to 16 houses each, due to reductions in the scope and funding of the project. The number of control houses, rather than the number of R&M houses, was reduced because the former (and in particular the modern urban houses) were expected to have less inter-house variability with respect to both blood lead and dust lead. This was borne out in the study findings.[3] Furthermore, two types of houses were originally planned for inclusion in the modern urban control group: houses in clusters of urban houses built after 1979, and houses in scattered sites, that had been extensively rehabilitated after 1979. When the sample size of modern urban houses was reduced to 16 houses, only the former were included as the negative (no lead paint) control group (see section 4.5 for additional descriptive information). It was expected that this type of cluster housing would reflect the lowest residential and ambient lead levels in the urban environment.

4.2 Repair & Maintenance Interventions and Comprehensive Abatement

R&M Levels I-III

The R&M interventions were financed by the Maryland Department of Housing and Community Development (DHCD) through a special loan program open to low-income owner-occupants and private property owners who rent their properties to low-income tenants. To meet DHCD loan eligibility requirements and the pre-requisites for R&M-type interventions imposed by the study, the three levels of R&M interventions were planned for study in lead-painted houses that had no structural defects and that were maintained according to the eligibility criteria listed in section 4.4. The R&M intervention costs were capped by DHCD as follows: R&M I, $1,650; R&M II, $3,500; and R&M III, $6,000 to $7,000. The last range is due to program criteria and pre-existing program agreements. It is important to note that the costs of the interventions in this project may not be generalizable to other settings and time periods due to differences in labor and material costs and overhead rates.

The three levels of intervention, described in detail elsewhere,[2] are described briefly below and in Table 1. R&M I included the following elements: wet scraping of peeling and flaking lead-based paint on interior surfaces; limited repainting of scraped surfaces; wet cleaning with a tri-sodium phosphate detergent (TSP) and vacuuming with a high efficiency particulate air (HEPA) vacuum to the extent possible in an occupied house; the provision of an entryway mat; the provision of information to occupants; and stabilization of exterior surfaces to the extent possible, given the project's budget cap. The R&M II interventions included two key additional elements: floor treatments to make them smooth and more easily cleanable and in-place window and door treatments to reduce abrasion of lead-painted surfaces. In addition to all of this, R&M III intervention included window replacement and encapsulation of exterior window trim with aluminum coverings as the primary window treatment, encapsulation of exterior door trim with aluminum, and more durable floor and stairway treatments. R&M households received cleaning kits for their own cleaning efforts. The kits each included a bucket, sponge mop, sponges, a replacement sponge mop head, a TSP cleaning agent, and an EPA brochure entitled "Lead Poisoning and Your Children."

Elements of Comprehensive Lead-Paint Abatement

The previously abated control houses received a comprehensive form of lead-paint abatement in demonstration projects in Baltimore between May 1988 and February 1991.[6,7] These comprehensive abatements included the following elements:

- Treatment of all lead painted ($\geq$0.7 mg/cm^2 or $\geq$0.5% lead by weight) surfaces primarily using replacement and enclosure methods;
- Minimal use of on-site paint removal methods;
- Fixing water leaks and other pre-existing conditions that would impediment effective abatement;
- Installation of vinyl replacement windows and enclosing of the exterior window trim with aluminum coverings;
- Making floors smooth and easily cleanable by the use of vinyl tile and sealant coatings;
- Door and stairway treatments, including replacement of lead-painted components;
- Cleaning by wet washing and the use of HEPA vacuum cleaners.

4.3 Recruitment And Enrollment

R&M study houses were identified from lists of addresses provided by owners of private rental properties in low-income neighborhoods of Baltimore and by City Homes, Inc., a non-profit housing organization, which owns and operates low-income rental properties to demonstrate methods of managing and maintaining such properties. The small number of owner-occupant properties in the R&M intervention groups (n=4) were identified through the KKRI's Lead Poisoning Prevention Program and outside sources. The previously abated houses were identified from lists of houses abated in past years as part of lead paint abatement demonstration projects conducted by Baltimore and KKRI. The modern urban houses built after 1979 were identified by house-to-house visits conducted in multiple clusters of such housing in Baltimore.

The enrollment process was done in two stages: pre-enrollment and formal enrollment. These activities were undertaken by study field workers who conducted extensive home visits (1,100 visits to more than 650 modern urban, previously abated, and candidate R&M houses) during the spring and summer of 1992. More than 90 percent of households identified as potentially eligible for the study indicated an interest in participating. Unfortunately, demographic data are not available to compare those households to households which did not express interest in participating. This pre-enrollment activity yielded 100 interested and eligible households for formal enrollment. Formal enrollment entailed obtaining signed informed consent statements for study participation from parents or legal guardians for both environmental and biological sampling. Separate consent statements were obtained for each child enrolled in the study using forms approved by the Joint Committee on Clinical Investigation of the Johns Hopkins Medical Institutions.

Between the time of formal enrollment and the commencement of the initial data collection campaign in January 1993, some enrolled households became ineligible, primarily due to the children growing too old to participate and the families moving to other dwellings. In some cases, the losses re-initiated pre-enrollment activity to identify an additional pool of potential study participants. The initial environmental sampling campaign in the modern urban and previously abated control houses was performed between January 1993 and July 1993. The baseline environmental sampling in R&M houses was conducted between March 1993 and November 1994.

4.4 Selection Criteria For Houses And Children

Houses and children were selected for participation in the study based on a rigid set of criteria. The first set of selection criteria listed below was applied to all five study groups. Additional selection criteria were applied to the three R&M groups and to the previously abated control group.

Selection criteria applied to all five study groups:

- House size was approximately 800 to 1,200 ft^2.

- The house was structurally sound without pre-existing conditions that could impede or adversely affect the R&M treatments and the safety of the workers and field staff (*e.g.*, roof leaks or unsafe floor structures). This criterion eliminated substandard housing in need of major renovation and, therefore, not suitable for R&M-type interventions. It also allowed a house to qualify for the special state loans that financed the R&M interventions.

- Utilities (heat, electric, and water) were available to facilitate interventions and field sampling.

- Each household included at least one child who was six months through 60 months of age at enrollment and was not mentally retarded or physically handicapped or had restricted movement. The house also had to be the child's primary residence (*i.e.*, the child was reported to spend at least 75 percent of time at the address). Also, the child's family had no definite or immediate plans to move at the time of enrollment.

- The house did not contain a large amount of furniture. This criterion allowed dust collection in all houses, as well as the intervention and cleanup efforts in occupied R&M houses.

<u>Additional selection criteria applied to R&M houses</u>:

- The house contained lead-based paint (defined in Maryland as ≥0.7 mg Pb/cm^2 or ≥0.5 percent lead by weight, as determined by wet chemical analysis) on at least one surface in a minimum of two rooms or, in the absence of testing, was constructed prior to 1941 (when lead-based paints were commonly used[19]).

- Interior house dust lead loadings, prior to intervention, exceeded Maryland's interim post-abatement clearance levels (*i.e.*, 200 $\mu g/ft^2$ for floors, 500 $\mu g/ft^2$ for window sills, and 800 $\mu g/ft^2$ for window wells) at a minimum of three locations.[33, c]

- The house had 12 or fewer windows needing R&M work. This was to allow for the implementation of the R&M interventions, given limited resources.

<u>Additional selection criterion applied to previously abated houses</u>:

- At least two pairs of pre-abatement and immediate post-abatement dust-wipe lead measurements from the same floor, window sill, and window well surfaces were available from previously collected data. This ensured that data were available to the R&M study on pre- and post-abatement baseline dust lead levels in these control houses.

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[c] In 1990, these clearance levels were adopted as interim post-abatement clearance levels by the U.S. Department of Housing and Urban Development (HUD). In 1995, HUD revised its interim clearance standard for floors to be 100 $\mu g/ft^2$.[4]

4.5 Characteristics Of Study Houses And Participants

The R&M houses and the previously abated houses are all scattered-site houses located in older residential neighborhoods in Baltimore. These study houses were built prior to 1941. More than 98 percent of the R&M houses and 100 percent of previously abated houses were rowhouses, which constitute the predominant type of housing in inner-city Baltimore neighborhoods. As mentioned previously, the 16 modern urban houses are rowhouses located in clusters built after 1979. The clusters of modern urban houses, which served as the sampling frames for this study, were all located in, or are adjacent to, urban housing neighborhoods constructed prior to 1941. Each cluster had multiple rows of housing built after 1979 and the rows generally extended the length of a city block. The characteristics of the study houses were typical of housing in low-income neighborhoods in Baltimore. Unfortunately, data do not exist to allow a comparison of dust lead levels in study homes to those in city homes in general.

Study houses generally were similar in terms of characteristics that might influence patterns of dust movement into and within a house (*i.e.*, overall size, number of windows, house type and design, condition, degree of setback from the street, and the presence of porches and yards).[3] The selection criteria ensured that the study houses would be similar in terms of size, number of windows, and, to some degree, overall condition. With regard to housing type, all five groups of houses consisted primarily of two-story rowhouses (not located at the end of the row) with two or three rooms on each level. Floor plans were produced for each study house to facilitate the sample collection activities. The proportion of carpet samples in composites was, on average, very low - essentially zero - in R&M I, R&M II, R&M III, and previously abated houses. On average, the proportion of carpets making up floor dust composites in modern urban houses was very high, averaging close to 100 percent. In all groups, differences were noted in the distribution of carpets between first and second stories.

Further, most study houses did not have porches (84 percent), were not located on narrow alleys (77 percent), and were not set back far from the street (77 percent). Houses with minimal set-backs had no front yards and entryways leading directly from the sidewalk, or from stairs ascending directly from the sidewalk. The other 23 percent of study houses were more than minimally set-back from the street, primarily due to the presence of porches or small front yards. Only four houses (3 percent) were classified as being set-back from the street by more than a modest amount as described above. Unlike the other four groups of houses, most of the modern urban control houses had yards in the front or back of the house. For this reason, exterior soil was available for collection at baseline from 69 percent of the modern urban houses, as opposed to only 15 percent of the R&M houses and 19 percent of the previously abated houses.

As reported previously,[3] a comparison of the 75 R&M houses to 27 R&M candidate houses that were sampled but not included in the study revealed no evidence of selection bias based on environmental lead concentrations, lead loadings, dust loadings or the blood lead concentrations of resident children.

4.6 Sample And Data Collection Procedures

Venous blood was collected from study children at the Kennedy Krieger Institute's Lead Poisoning Clinic by a pediatric phlebotomist into 3 mL Vacutainers® with EDTA added as an anticoagulant. Information on the study children and their households was collected using a structured interview questionnaire. Trained field teams administered the questionnaires and collected all environmental samples, including field quality control (QC) samples.

Settled house dust was collected using a modified high-volume cyclone sampler originally developed for EPA for the evaluation of pesticide residues in house dust.[34] The modified device, referred to as the R&M cyclone, is described in detail and characterized elsewhere.[20,21] The device consists of a Teflon®-coated cast aluminum cyclone attached to hand-held Dirt Devil® vacuum as the air mover for the system. A 100 mL Teflon® microwave digestion liner was used as the sample collection container to eliminate a sample transfer step in the laboratory, thereby reducing the risk of sample loss.

The sampling plan for settled dust included the collection of three composite floor dust samples in each of the houses at each campaign: one composite in rooms with windows on the first story, one composite in rooms with windows on the second story, and one composite in first and second story rooms without windows. Each composite was composed of samples collected from two randomly selected 1 ft^2 (929 cm^2) perimeter floor locations in each appropriate room. If a randomly selected location were carpeted or covered with an area rug, this information was recorded on the sample collection form and the carpet or rug was sampled using the R&M cyclone. Settled dust also was collected in two composite window sill samples and two composite window well samples in each house at each sampling campaign. Samples were composited by story from all windows available for sampling. Examples of windows not available for sampling were those with window air conditioners and those blocked by furniture. Settled dust also was collected as individual (*i.e.*, not composite) samples from horizontal portions of air ducts, from interior and exterior entryways, and from the main item of upholstered furnishing in each house.

Three individual soil core samples were collected from the top 0.5 inch (1.3 cm) of soil from three randomly selected locations at the drip-line and then combined as one composite sample. Each soil core was collected into a polystyrene liner using a six-inch (15.2 cm) stainless steel recovery probe.

Drinking water samples were collected as two-hour fixed-time stagnation samples from the kitchen faucet. This procedure involved running the cold water for at least two minutes to flush the pipes and, after a two-hour interval, collecting the first flush of water in a 500 mL polyethylene bottle. A list of field sample types is provided in Table 6.

Table 6: Types Of Field Samples

Sample Type	Sampling Locations/Specifics
Perimeter Floor Composite Settled Dust	First story and second story rooms with windows; rooms without windows
Window Sill Composite Settled Dust	First and second story
Window Well Composite Settled Dust	First and second story
Air Duct/Upholstery Settled Dust	Upholstery was sampled if air ducts were unavailable
Interior Entryway Settled Dust	Not directly on entryway mat
Exterior Entryway Settled Dust	Not directly on entryway mat
Soil Core	Drip-line composite
Drinking Water	Kitchen faucet
Field QC	Blanks and duplicates for all field sample types

Families were informed by letter of the results of dust lead and blood lead tests from each campaign. Results of dust tests were provided on a qualitative basis with recommendations for housekeeping priorities to address areas with high lead loadings. Additionally, letters were sent to the parents/guardians of the study children with the results of the blood lead tests to be shared with the child's primary care provider. All blood lead test results were reported to the Maryland Blood Lead Registry, as required by Maryland law.

5.0 LABORATORY ANALYSIS PROCEDURES

Interior and exterior settled dust, exterior soil, water and venous blood samples were analyzed at the Kennedy Krieger Research Institute's Trace Metal Laboratory using established analytical methods. Closed vessel microwave digestion was used for dust, soil, and water samples, according to modified SW 846 Methods 3015 and 3051. Analysis of dust digestates was performed using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP), according to SW 846 Method 6010 and/or Graphite Furnace Atomic Absorption Spectrometry (GFAA), according to SW 846 Method 7421. Soil and drinking water were analyzed by GFAA according to SW 846 Method 7421. Venous blood was analyzed by GFAA and by anodic stripping voltammetry (ASV).[35] Table 7 summarizes these procedures.

Table 7: Summary Of Laboratory Procedures

Sample Type	Pre-Preparation	Preparation	Analysis
Dust	Drying and gravimetrics	Microwave digestion using 1:1 HNO_3: H_2O	ICP/GFAA[a]
Soil	Drying, sieving and homogenization	Microwave digestion using 1:1 HNO_3: H_2O	GFAA
Drinking Water	Acidified	Microwave digestion using 1:1 HNO_3: H_2O	GFAA
Blood	Stabilized in EDTA after collection	Addition of matrix modifier/Triton X-100 solution	GFAA/ASV[b]

[a] Samples with lead concentrations below the limit of quantitation of the ICP instrument were analyzed by GFAA.

[b] ASV used in addition to GFAA for rapid reporting of blood lead

6.0 DATA PROCESSING AND STATISTICAL ANALYSIS PROCEDURES

6.1 Data Processing

Data analyzed as a part of this study were derived from field collection forms, laboratory instruments, and questionnaires. Raw data of all types were transferred to the data manager who uploaded the data to a VAXStation 3100 computer for later analysis. A summary of the data processing steps employed for the three sources of data is presented below.

- The field data consist of all data recorded on the field collection forms for settled dust, soil, and drinking water samples, as well as room and window inventory data and general study data. Data were entered twice for verification from the field forms into ASCII data files by a commercial data entry firm. These raw data files were transferred to the data management team for management, storage, and later analysis. Field data forms were checked for completeness and accuracy by the outreach coordinator and data manager prior to data entry. Data were verified again by laboratory staff from final SAS® file printouts.

- Laboratory data were electronically stored by each laboratory instrument. Gravimetric data (tared and loaded weights for dust and soil samples) were generated and stored by the Mettler Balance. Lead concentration measurements for dust samples were made and recorded by the ICP. Lead content in drinking water, soil, and blood, as well as dust samples with low lead concentrations, were measured by GFAA. Electronically stored laboratory data from the Mettler, ICP, and GFAA instruments were imported to Paradox® (v.4.0) by laboratory staff for tracking of samples. Paradox® data were then converted to ASCII files by the data management team for uploading to the VAXStation. A SAS® program read in the laboratory data for environmental and blood samples and created SAS® data sets for data analysis. The data were verified again by laboratory staff from final SAS® file printouts.

- Questionnaire data forms were entered twice for verification by a data entry firm into ASCII data files. These raw data files were verified in-house and transferred to the data manager. A SAS® program read in the raw data and created SAS® data sets for analysis.

6.2 Data Summary

Environmental dust data from four surface types (perimeter floor, window sill, window well, and interior entryway) included in <u>each</u> of the first five data collection campaigns (pre-R&M, post-R&M, two months post R&M, six months post R&M, and twelve months post-R&M) are included in this report as well as data collected less frequently (i.e., airduct dust, upholstery dust, soil, and water). Tables 8 and 9 display the types and numbers of 12-month campaign samples planned, collected, and analyzed for lead, by study groups, for the 104 active houses included in this report.

Table 8: **Types And Numbers Of Samples Collected And Analyzed For Lead (Excluding QC Samples) As A Part Of The 12-Month Campaign**

Sample Type	Planned per House	Collected in 104 Active Houses	Collected and Analyzed for Lead	Unavailable Samples in the 104 Active Houses
Perimeter Floor Dust Composite in Rooms with Windows	2[a]	212	212	0
Perimeter Floor Dust Composite in Rooms without Windows	1	55	55	49[c]
Window Sill Dust Composite	2[a]	207	207	1[d]
Window Well Dust Composite	2[a]	203	203	5[e]
Interior Entryway Dust	1	104	104	0
Exterior Entryway Dust	-	-	-	
Air Duct Dust	1[b]	57	57	1[f]
Upholstery Dust	-[b]	46	46	0
TOTAL DUST	9	884	884	56
Soil Core - drip line				-
Drinking Water	-	-	-	-
Venous Blood	1/child	126	126	-
GRAND TOTAL	≥10	1010	1010	56

a One composite sample was obtained per story. Some houses had samples in basements used as living spaces.
b Upholstery samples were collected if air duct samples could not be obtained.
c 49 houses did not have rooms without windows.
d Sills on one story were inaccessible in one R&M I house.
e Wells on one story were inaccessible in five instances in R&M I houses.
f Air duct & upholstery were inaccessible/not present in one R&M II house (see footnote b).

Table 9: Types And Numbers Of Samples Collected By Group (Excluding QC Samples) As A Part Of The 12-Month Campaign[a]

Sample Type	Collected in 15 Modern Urban Houses	Collected in 14 Previously Abated Houses	Collected in 25 R&M I Houses	Collected in 23 R&M II Houses	Collected in 27 R&M III Houses
Perimeter Floor Dust Composite in Rooms with Windows	31	28	53[b]	46	54
Perimeter Floor Dust Composite in rooms without windows	4	6	17	15	13
Window Sill Dust Composite	30	28	49	46	54
Window Well Dust Composite	30	28	45	46	54
Interior Entryway Dust	15	14	25	23	27
Exterior Entryway Dust			-		-
Air Duct Dust	11	5	10	15	16
Upholstery Dust	4	9	15	7	11
TOTAL DUST	125	118	214	198	229
Soil Core - drip line	-		-	-	-
Drinking Water		-	-	-	-
Venous Blood	14	24	24	30	34
TOTAL	139	142	238	228	263

a Two R&M II houses were reclassified to R&M III on the basis of the actual work done in the house at the time of intervention.

b Includes two samples collected in basements used as living spaces.

Some of the original study households moved or voluntarily withdrew from the study between the initial and the 12-month data collection campaigns. Table 10 reports the frequency of moves for each study group and the numbers of replacement households enrolled among families moving into vacated study houses. Approximately 20 percent (21 out of 107) of the original families in the 107 original study houses moved prior to the 12-month campaign. By the end of the 12- month campaign, all but three of these study families were replaced by the next family that moved into the house. Despite our success in gaining the participation of these new families, they had fewer eligible children than the original families. By the end of the 12-month campaign, the study also had gained nine children who were newborns that became of age (≥6 months) for blood lead testing and two other eligible children who joined study households. It is hoped that future campaigns will provide sufficient longitudinal data on children born into study houses to allow for a separate analysis of this subgroup, which would help to increase our understanding of the role of R&M interventions in the primary prevention of lead poisoning.

One R&M II house was vacant at the time of the 12-month sampling. None of the houses included in this report are known to have had any major renovations or repairs during the first year of follow-up. One R&M I house had its front and back doors replaced due to break-ins that damaged the original doors, and in another house, the wallpaper was removed by the occupants from the first floor rooms using a steam process.

6.3 Statistical Analysis

This section describes the statistical methods employed in the analysis of data from the first year of follow-up. The first section describes the methods used to generate descriptive statistics and graphical displays of the data. The second section provides an overview of the statistical method used for the analysis of longitudinal data. The last section describes the use of factor analysis as a method for combining individual sample readings in a house and specifies the longitudinal models fitted to the dust and blood data.

SAS[36] PROC MIXED software (version 6.09E) was used for longitudinal data analysis. Interpretation of the estimates obtained by the mixed model obey the usual rules of interpretation of regression coefficients, i.e., the coefficient of a covariate is the expected change in the response variable associated with a unit change in the covariate in the presence of the other covariates. When the covariate is a dummy variable, a unit change in the covariate corresponds to the expected difference between the response at the level of the covariate compared to the omitted level.

For data analysis purposes, lead values less than the instrument detection limit (IDL) were coded as the IDL/$\sqrt{2}$.[37] For lead values less than the limit of quantitation (LOQ), but greater than the IDL, the observed value was used in the data analysis. Also, one child in a previously abated house had a blood lead increase to a concentration of 53 μg/dL at the 12-month campaign and was provided with chelation therapy. This child is an outlier in this study and was excluded from the statistical data analysis relating blood lead to dust lead.

Table 10: Family Moves, Reoccupancies, And New Subjects Enrolled Between The Initial Campaign And The 12-Month Campaign.

Study Group	Moved		Replaced		Other Children	
	Households	Children[a]	Households	Children	New member of household	Newborns
R&M I (25 houses)	6	16	6	2	0	3
R&M II (23 houses)	6	10	5	8	0	2
R&M III (27 houses)	6	9	6	8	0	1
Modern Urban (16 houses)	1	4	1	0	0	0
Previously Abated (16 houses)	2	6	0	0	2	3
Total	21[b]	45	18	18	2	9

[a] Includes children/families who moved although other members of household remained.

[b] This number represents 20 percent of the original study households.

Descriptive Statistics

The study outcome variables were dust lead concentration ($\mu g/g$), dust lead loading ($\mu g/ft^2$), dust loading (mg/ft^2) and blood lead concentration ($\mu g/dL$). The main study variables included study group, data collection campaign, type of environmental sample (e.g., dust, water), and surface type (e.g., floor, window sill, window well, entryway, upholstery). A Shapiro-Wilk Test indicated that the distributions of the dust and blood lead data were skewed.[38] As expected, use of the log transformation reduced the amount of skewness and produced histograms and boxplots that were approximately normal (Figures 1-13). Descriptive statistics on blood and dust were produced after transforming the data using the natural logarithm (ln).

A further characteristic of the data set is the repeated measures from a house, which violate the assumption of independence invoked for most analyses. To overcome this problem, a mixed-effects model was used to account for the correlation of samples within a house. These calculations result in a better estimate of the mean and confidence interval for the settled dust from floors in rooms with windows, window sills, window wells, and children's blood. These calculations were done by study group and surface type.

Descriptive statistics for all dust sample types are presented in Appendix A. Tables 16-18 display descriptive statistics for blood, soil and water. Since multiple observations were available in each of the houses for settled dust from window sills, and window wells, floors in rooms with windows, as well as for children's blood, additional analysis was performed using SAS® PROC MIXED with house as a random effect to address the issue of clustering (i.e. multiple observations per house). Geometric mean values, standard errors, and 95 percent confidence intervals were obtained using the intercept models fitted separately for each study group, surface type (floors in rooms with windows, window sills, window wells), and matrix (dust, blood).

Side-By-Side Boxplots

Side-by-side boxplot figures with median traces are presented in this report as a means of displaying lead levels across campaigns within and between study groups. In a boxplot display, 50 percent of the data is contained in the box shown in the figure; the bottom of the box is the lower quartile and the top of the box is the third quartile, the horizontal line inside the box represents the sample median. The vertical lines extending from the box represent the expected lower and upper range of the data, based on the variability of the central portion of the data. The fences are 1.5 interquartile ranges from the upper and lower edges of the box. Extreme values are indicated by an asterisk.[39] The widths of the boxes in any given side-by-side boxplot are proportional to the number of observations. The descriptive statistics presented in this report include "extreme values" that are indicated by the symbol '*' in the boxplot displays.

Statistical Method for Analysis of Longitudinal Data

Statistical methods for the analysis of longitudinal data have developed rapidly over the last decade.[40-46] These methods, which are natural extensions of multiple regression and analysis of variance, are extremely flexible. Current longitudinal methods allow for the inclusion of random and fixed effects, longitudinal (time-dependent) covariates and constant covariates, as well as for discrete and continuous covariates, all in a multiple regression context. In this study, for example, we have the following types of covariates:

- study group - fixed effect, discrete
- house - random effect, discrete
- dust lead - fixed time dependent continuous covariate
- child - random effect, discrete
- campaign   fixed time dependent covariate, discrete
- age of child   fixed time dependent covariate
- season - fixed discrete covariate

The response variable modeled was dust lead reading or blood lead concentration (log-transformed). These response variables, as well as their associated covariates, have been and will be observed at times described in Table 5.

For the dust lead measurements let Y_i denote the vector of responses over time for the *I*-th house, i.e., Y_i is an n_i x vector of the form $Y_i = (y_{i1}, y_{i2}, \ldots, y_{in})^T$ where y_{ij} is the response for the *I*-th house at time t_j and "T" stands for the transpose operation. Then, the general form of the model is:

$$Y_i = X_i\beta + Z_i b_i + \epsilon_i \qquad \text{(Eq.1)}$$

where X_i is an n_i xp matrix of covariate values for the fixed effects, β is a px1 vector of parameters for the fixed effects, Z_i is an $n_i$xq matrix of covariate values for the random effects, b_i is a qx1 vector of random effect parameters and ϵ_i is an n_ix1 vector representing random error.

Estimates of the parameters in the overall model are obtained using the methods outlined in published papers.[40-46] The essential feature of these methods is the use of weighted least squares with a "working" estimate of the covariance matrix followed by iteration with an updated estimate of the covariance matrix until convergence. The estimate of the variance-covariance matrix of the fixed effects is robust, in the sense that it is consistent, regardless of the form of the "working" estimate of the covariance matrix. The model for blood lead is similar to the above model, specified for each child.

Our primary interest in this study is in the parameters of the model that represent the effect of R&M interventions on dust lead and blood lead. The fact that this model allows estimation of these parameters in the presence of heterogeneity between houses and temporal correlation, and produces variance estimates that are robust, is extremely important.

The general nature of the model makes it ideal for a study of this type where there is the potential for unbalance. Since the model is house-specific or child-specific, depending on whether dust lead or blood lead is being modeled, we do not require that the number of observations through time be equal. Thus, should a child move or otherwise be eliminated from the study, the house data can be analyzed while the data for that child can be included up to the point of departure. Should another child be entered into the study at that house, his or her blood lead readings can be included in the blood lead analysis for the remainder of the study, thus providing partial information for that child. The common residence of the children is included in the house covariate, which allows for correlation structure between these observations.

Age-related effects in the analysis of blood lead concentration responses need to take into account the fact that blood lead is not linearly related to age, since it tends to increase between six months and two years and decrease slowly among children over two years of age. This is done by the use of linear and quadratic terms for age in the model. The presence of several children in a house, which introduces another source of correlation, (i.e. between children in the same house) is accounted for by using the house as a random effect, which introduces the required correlation.

Specifications of Longitudinal Models for Dust

In the analysis of the data from the first year of follow-up, we have fit the statistical models proposed in the Quality Assurance Project Plan.[2] The results of the compositing self study indicated that an overall measure of lead exposure could be considered with little loss of information.[47] Factor analysis confirms this as described below. This was true for both dust lead concentrations, lead loadings and dust loadings. These results suggest that the readings from multiple sample sites in a house can be combined to produce an overall measure to use as a covariate in the model relating environmental lead to blood lead. Consequently, we have explored the use of factor analysis as a method for combining individual sample results. The use of the results of exploratory factor analysis to guide the construction of variables for analysis is a standard approach used in data analysis. Our general approach is outlined below:

- Data for floors in rooms with windows, window sills and window wells were used in the analysis. These data were composited across stories in a house in the calculation of weighted averages for each of the three dust endpoints, for each house, and for each campaign.

- The weighted averages were transformed using natural logarithms.

- Factor analysis was first performed for each dust endpoint by campaign and then again not broken out by campaign. The latter results were then used in the longitudinal analysis. These steps were repeated anew for each analysis because of the different combination of study groups and campaigns for intervention and for control houses.

Occasionally, a composite was incomplete because a sill or well was not accessible. On a very few occasions, all sills or wells in a single story were inaccessible and, thus, no composite value was available. If both first and second story composites were missing, no attempt was made to estimate missing data.

The results indicate that:

- The first factor (factor1) accounts for 64 percent to 82 percent of the variability of environmental dust lead across campaigns, when all five groups are analyzed together, and 54 percent to 65 percent of the variability, when the three R&M groups are analyzed separately (Table 11).

- The second factor (factor2) characterizes the difference between the floor lead measurements and the window sill and window well lead measurements and accounts for 12 percent to 26 percent of the variability, when all five groups are analyzed together, and 22 percent to 31 percent of the variability, when the three R&M groups are analyzed separately (Table 11).

Thus far, the percentages of the variability of the dust readings accounted for by the factor loadings have remained relatively stable over study groups and campaigns (Table 11). The factor patterns for all five groups also were stable over time (Table 12). The factor patterns for the three R&M groups by surface type across campaigns also were consistent over time, except for factor2 at the initial campaign (Table 13). The latter may be different due to the fact that half of the R&M houses were vacant at the time of the initial campaign and/or to an intervention effect on factor patterns. Table 13 also shows that the factor patterns are consistent within campaigns for the three types of dust measurements. Both factor1 and factor2 are normally distributed.

Given the stability of the factors over time, we used them as the variable to measure environmental lead levels. The first factor was used as the dependent variable in the longitudinal data analysis of the three dust endpoints. This factor reflects the campaigns up to, and including, the 12-month campaign. We found that the use of the first factor in the data analysis explains more of the variability in the dust endpoints, as compared to raw average or to weighted average measures.

Table 11: Variability Accounted for by Factor Loadings Across Campaigns

Five Study Groups Combined:

Dust Measure	Initial Campaign		Six-Month Campaign		12-Month Campaign	
	factor1	factor2	factor1	factor2	factor1	factor2
Lead Loading	.81	.14	.68	.23	.64	.26
Lead Concentration	.82	.12	.73	.20	.65	.22
Dust Loading	.65	.24	.60	.24	.55	.32

Three R&M Groups:

Dust Measure	Initial Campaign		Post-Intervention Campaign		Two-Month Campaign		Six-Month Campaign		12-Month Campaign	
	factor1	factor2	factor1	factor2	factor1	factor2	factor1	factor2	factor1	factor2
Lead Loading	.56	.29	.65	.22	.59	.31	.65	.26	.58	.31
Lead Concentration	.57	.28	.59	.29	.59	.28	.64	.27	.54	.31
Dust Loading	.58	.26	.55	.26	.57	.31	.62	.25	.56	.32

Table 12: Factor Patterns For The Five Study Groups Across Campaigns

Dust Measure	Surface Type	Campaign					
		Initial		Six-Month		12-Month	
		factor1	factor2	factor1	factor2	factor1	factor2
Lead Loading	Floor	0.87	0.48	0.71	0.70	0.68	0.72
	Sill	0.95	-0.09	0.90	-0.23	0.89	-0.17
	Well	0.90	-0.37	0.87	-0.34	0.84	-0.40
Lead Concentration	Floor	0.88	0.45	0.73	0.67	0.74	0.67
	Sill	0.93	-0.09	0.91	-0.25	0.85	-0.30
	Well	0.94	-0.35	0.90	-0.30	0.85	-0.28
Dust Loading	Floor	0.76	0.62	0.71	0.70	0.49	0.85
	Sill	0.90	-0.06	0.81	-0.24	0.88	-0.08
	Well	0.80	-0.52	0.79	-0.38	0.80	-0.44

Table 13: Factor Patterns For R&M Groups Across Campaigns

		Campaign									
Dust Measure	Surface Type	Initial		Post-Intervention		Two-Month		Six-Month		12-Month	
		factor1	factor2	factor1	factor2	factor1	factor2	factor1	factor2	factor1	factor2
Lead Loading	Floor	0.82	-0.29	0.76	0.61	0.49	0.87	0.57	0.82	0.40	0.91
	Sill	0.82	-0.27	0.87	-0.07	0.90	-0.13	0.88	-0.30	0.90	-0.12
	Well	0.55	0.83	0.79	-0.51	0.86	-0.36	0.90	-0.23	0.87	-0.29
Lead Concentration	Floor	0.76	-0.47	0.51	0.86	0.57	0.82	0.53	0.84	0.40	0.91
	Sill	0.82	-0.14	0.88	-0.19	0.86	-0.30	0.90	-0.22	0.86	-0.22
	Well	0.63	0.76	0.85	-0.32	0.87	-0.24	0.89	-0.29	0.86	-0.21
Dust Loading	Floor	0.82	-0.28	0.73	-0.55	0.49	0.85	0.66	0.74	0.38	0.92
	Sill	0.81	-0.33	0.80	-0.08	0.88	-0.09	0.86	-0.18	0.89	-0.09
	Well	0.65	0.76	0.68	0.69	0.80	-0.43	0.81	-0.41	0.85	-0.32

Consequently, the following models were fit to the dust data (see Table 14 for definitions of variables)[d]

Environmental Model:

$$
\begin{aligned}
factor1_{ijkl} = \; & \beta_0 + \beta_1{*}season_{ij} + \beta_2{*}group_{ik} \\
& + \beta_3{*}campaign_l + \beta_4\, group_{ik}{*}campaign_l \\
& + b_i{*}house_i + \epsilon_{ijkl} \qquad \text{(Eq.2)}
\end{aligned}
$$

where,
"i" refers to house, "j" to season, "k" to study group, "l" to campaign, group*campaign to the interaction of group and campaign. Following standard practice, regression coefficients corresponding to "fixed effects" are denoted by Greek letters, while regression coefficients corresponding to "random effects" are denoted by non-Greek letters (e.g. b).

This model was fit to the lead concentration, lead loading and the dust loading data. The models were run using all five study groups and then again using just the three R&M groups in order to include the post-intervention and two-month campaign data in the analysis.

Specifications of longitudinal models for blood lead

To address the study objectives with regard to blood lead, we fit two main types of models to the data. The first model, referred to as the exposure model, was used to characterize the relationship between blood lead and dust lead (both dust lead concentrations and lead loadings). In this model, the two dust lead factors were included as dependent variables, along with demographic and behavioral variables. The second model, referred to as the comparison model, was used to investigate blood lead concentrations across groups and within groups over time.

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[d] Our exploratory analysis indicated that the covariance structure varied little over time. Therefore, when fitting the longitudinal models using SAS Proc Mixed, we used the random statement that built in the necessary covariance structure.

Table 14: Definitions of Variables

Variable	Definition
factor1	Linear combination of floor, window sill and window well data (composite measure of exposure in a house).
factor2	Linear combination of floor, window sill and window well data (represents the difference between floor and window values).
age	Child's age in months
mouthing	The sum of four questionnaire variables dichotomized into a low/high variable
season	Fall: September 21 through December 20 Winter: December 21 through March 20 Spring: March 21 through June 20 Summer: June 21 through September 20

The two models are as follows:

Exposure Model

$$ln(PbB)_{iklm} = \beta_0 + \beta_1{*}factor1_{iklm} + \beta_2{*}factor2_{iklm} + \beta_3{*}age_{iklm} + \beta_4{*}age^2_{iklm} + \beta_5{*}summer_{iklm} + \beta_6{*}campaign_l + b_i{*}house_i + b_{m(l)}{*}child_{m(l)} + \epsilon_{iklm} \quad \text{(Eq.3)}$$

where,
"i" refers to house, "k" to group, "l" to campaign, "m" to child within house, group*campaign to the interaction of group and campaign. Regression coefficients corresponding to "fixed effects" are denoted by Greek letters, while regression coefficients corresponding to "random effects" are denoted by ordinary letters (e.g. b).

The initial campaign blood and dust lead values for children who moved into the vacant R&M II and R&M III houses after intervention were excluded from the exposure model. Their initial blood lead values at the time they moved in reflect body burdens associated with exposures in their past living environments, not in their new home environments.

Study group was left out of the exposure model because of its association with our exposure variables. This model was run using all five study groups and then again using the three R&M groups. Due to the consistency of the factor patterns noted above across campaigns, the interaction between factor1 and campaign and between factor2 and campaign were not found to be statistically significant and were dropped from later applications of the model. Other variables such as gender and mouthing variables were added to this basic model.

Comparison Model

$$ln(PbB)_{iklm} = \beta_0 + \beta_1{*}age_{iklm} + \beta_2{*}age^2_{iklm} + \beta_3{*}summer_{iklm} + \beta_4{*}male_{iklm} + \beta_5{*}group_k + \beta_6{*}campaign_l + b_i{*}house_i + b_{m(l)}{*}child_{m(l)} + \epsilon_{iklm} \quad \text{(Eq.4)}$$

(Refer to the exposure model above for an explanation of the notation used in Eq.4).

The comparison model was fit separately for children with blood lead concentrations $<20\mu g/dL$ and $\geq 20\mu g/dL$. According to CDC guidelines, children with blood lead concentrations $\geq 20\mu g/dL$ should be referred for medical evaluation and management.[10] Table 15 displays the numbers of children included in these models by initial blood lead concentration and by group. Although most children with baseline blood lead concentrations $\geq 20\mu g/dL$ were in R&M II and R&M III, the variances of baseline blood lead concentrations across the three groups were essentially the same. Descriptive statistics and box plots of baseline blood lead concentrations by study group are displayed in Appendix B.

Table 15: Numbers of Children With Initial Blood Lead <20μg/dL and ≥20μg/dL

Study group	Initial Blood Lead <20 μg/dL (n)	Initial Blood Lead ≥20 μg/dL (n)
R&M I	34	1
R&M II	27	7
R&M III	29	8
Previously Abated	20	3
Modern Urban	20	0

The group*campaign interaction term and the gender and mouthing variables were not statistically significant. It should be noted that although the model includes a term for child within house, there were in actuality small numbers of households that had more than one child per house.

Measurement Error

A number of researchers have raised the issue of measurement error in environmental variables. Measurement errors in the covariates or explanatory variables can affect the magnitude of the estimated regression coefficients in linear models. This effect is called attenuation and implies that observed effects are underestimated by an amount related to the magnitude of the errors in the covariates. The modeling approach used in our analysis uses factor analysis to derive environmental measures from the basic environmental samples. The use of latent variables implicit in the measurement error models is thus present in our approach where these variables are explicitly treated as part of the model. While measurement error is present in the environmental samples, we believe that the approach using factor analysis adequately accounts for the presence of measurement error.

7.0 RESULTS

This section is divided into three parts. The first part provides descriptive statistics on environmental data and blood data from the first year of follow-up, including a series of side-by-side boxplot figures with median traces to graphically display trends across time. The second part presents descriptive statistics on data derived from the 12-month campaign and an analysis of the correlations between children's blood lead concentrations and their dust lead exposure (section 7.2). These descriptive statistics do not take into account season or any other potential covariates. Part three presents findings of the longitudinal data analysis and includes a summary of the statistical significance of trends in dust lead and blood lead over time within and across groups (section 7.3).

7.1 Descriptive Statistics For The First Year Of Follow-Up

Side-by-Side Boxplots With Dust Data

Figures 1-12 show the distributions of dust lead loadings, dust lead concentrations, and dust loadings by study group across campaigns for each of four main surface types. The boxplots are displayed on the log scale, due to the wide ranges of dust values between groups and within groups across time (see section 6.3 for an explanation of the components of a boxplot). These figures reveal the following trends:

- Median traces for dust lead loadings across surface types show a pattern of maximally reduced levels at post-intervention. This pattern is most pronounced for R&M III houses, intermediate for R&M II houses, and smallest for R&M I houses. At two months, lead loadings were increased over post-intervention levels, but they were below pre-intervention levels. They remained below pre-intervention levels through six months and 12 months of follow-up. At six months and 12 months, median lead loadings were relatively stable, or moderately increased, in R&M I and II houses across surface types, while in R&M III houses, median lead loadings tended to be relatively stable or moderately decreased (Figures 1-4). Deviations from this pattern were evident for floors and entryways of R&M I and R&M II houses in which lead loadings did not increase at two months.

- Median traces for dust lead concentrations reveal a downward trend at post-intervention and at two months across sample types. This trend was most pronounced in R&M III houses, intermediate in R&M II houses, and least pronounced in R&M I houses. At six and 12 months, lead concentrations remained relatively stable or slightly increased in R&M I houses and relatively stable or moderately decreased in R&M II and R&M III houses (Figures 5-8).

- The median traces for dust loadings show a pattern of reductions at post-intervention that was greatest in R&M III houses, intermediate in R&M II houses, and smallest in R&M I houses (Figures 9-12). At two months, dust loadings tended to reaccumulate over the post-intervention loadings, but median loadings generally remained below pre-intervention levels throughout the first year of follow-up.

- The modern urban and previously abated control houses show a pattern of relatively stable median lead loadings, lead concentrations, and dust loadings. There is a slight downward trend at six months and 12 months in lead loadings and dust loadings (Figures 1-12).

Side-By-Side Boxplots Of Blood Lead Concentrations

Figure 13 provides boxplot displays of unadjusted blood lead concentrations by study group for children with initial blood lead concentrations <20 μg/dL. The child with a blood lead concentration of 53 μg/dL in the previously abated group at 12 months does not appear on the figure. The median traces for all five study groups, unadjusted for covariates, indicate little change over time.

"Hair Clip" Line Plots With Blood Lead Concentrations for Individuals

Figures 14-18 are "hair clip" line plots of blood lead concentrations for individual children in each of the five study groups. These figures display each study child's unadjusted blood lead concentrations during the first year of follow-up. As seen in these plots, most of the children with baseline blood lead concentrations ≥20 μg/dL were in the R&M II and R&M III study groups. Children with baseline blood lead concentrations ≥20 μg/dL experienced reductions in their blood lead concentrations over time, while those with baseline blood lead concentration <20 μg/dL tended to remain <20 μg/dL during the first year of follow-up.

7.2 Descriptive Statistics At The 12-Month Campaign

Blood Lead Concentrations At 12 Months

Table 16 provides descriptive statistics for children's blood lead concentrations by group at the 12-month campaign. The unadjusted geometric mean blood lead concentrations were 8 μg/dL for children in R&M I houses, 11 μg/dL for children in R&M II houses, and 12 μg/dL for children in R&M III houses, 12 μg/dL for children in previously abated houses and 3 μg/dL for children in modern urban houses. The mean age of children across the five groups at the 12-month campaign ranged from 39 months to 44 months.

Dust Lead Loadings, Lead Concentrations And Dust Loadings At The 12-Month Campaign

Descriptive statistics for settled dust at the 12-month campaign are graphically displayed as bar graphs showing geometric mean dust lead loadings ($\mu g/ft^2$), dust lead concentrations (μg/g), and dust loadings (mg/ft^2) by group and by surface type in Figures 19 to 21. Tables with descriptive statistics (geometric mean, n, minimum, maximum, standard deviation) for lead loadings, lead concentrations and dust loadings by group and by surface type are in Appendix A.

Table 16: Descriptive Statistics For Blood Lead Concentrations By Group At The 12-Month Campaign

Study Group	n	Minimum (μg/dL)	Maximum (μg/dL)	Geometric Mean[a] (μg/dL)	S.D. on log scale	Lower 95% CI for GM (μg/dL)	Upper 95% CI for GM (μg/dL)
R&M I	24	2	20	8	0.538	6	10
R&M II	30	4	31	11	0.422	10	13
R&M III	34	4	30	12	0.480	10	14
Previously Abated	24	1	53[b]	12	0.731	8	18
Modern Urban	14	2	6	3	0.371	3	4

a GM values and confidence intervals were obtained from SAS® PROC MIXED

b This outlier was excluded from the longitudinal data analysis (see section 6.3)

Figure 1 Dust Lead Loadings (PbD in ug/ft^2) across Campaigns for Floor Surfaces

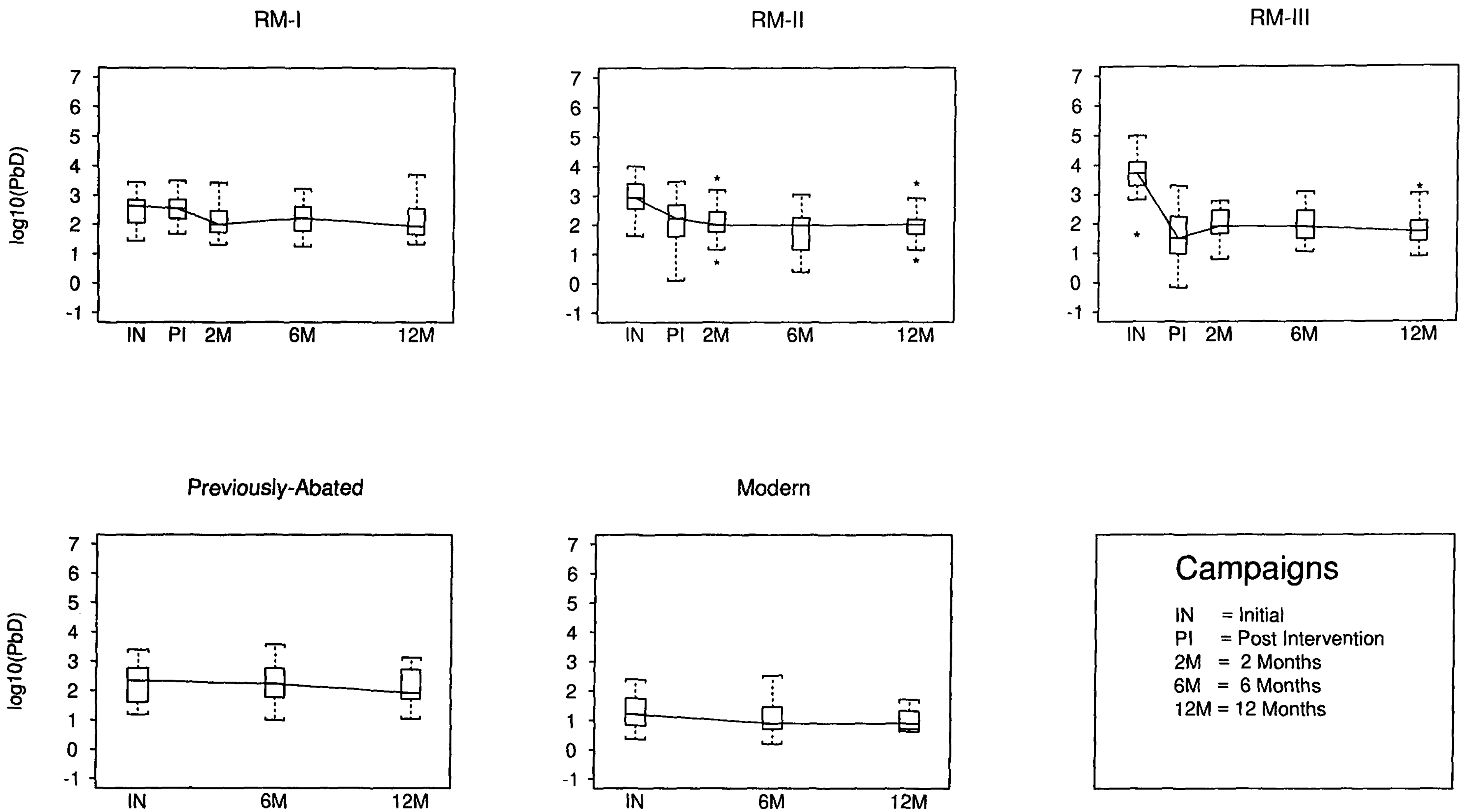


Figure 2 Dust Lead Loadings (PbD in ug/ft^2) across Campaigns for Window Sill Surfaces

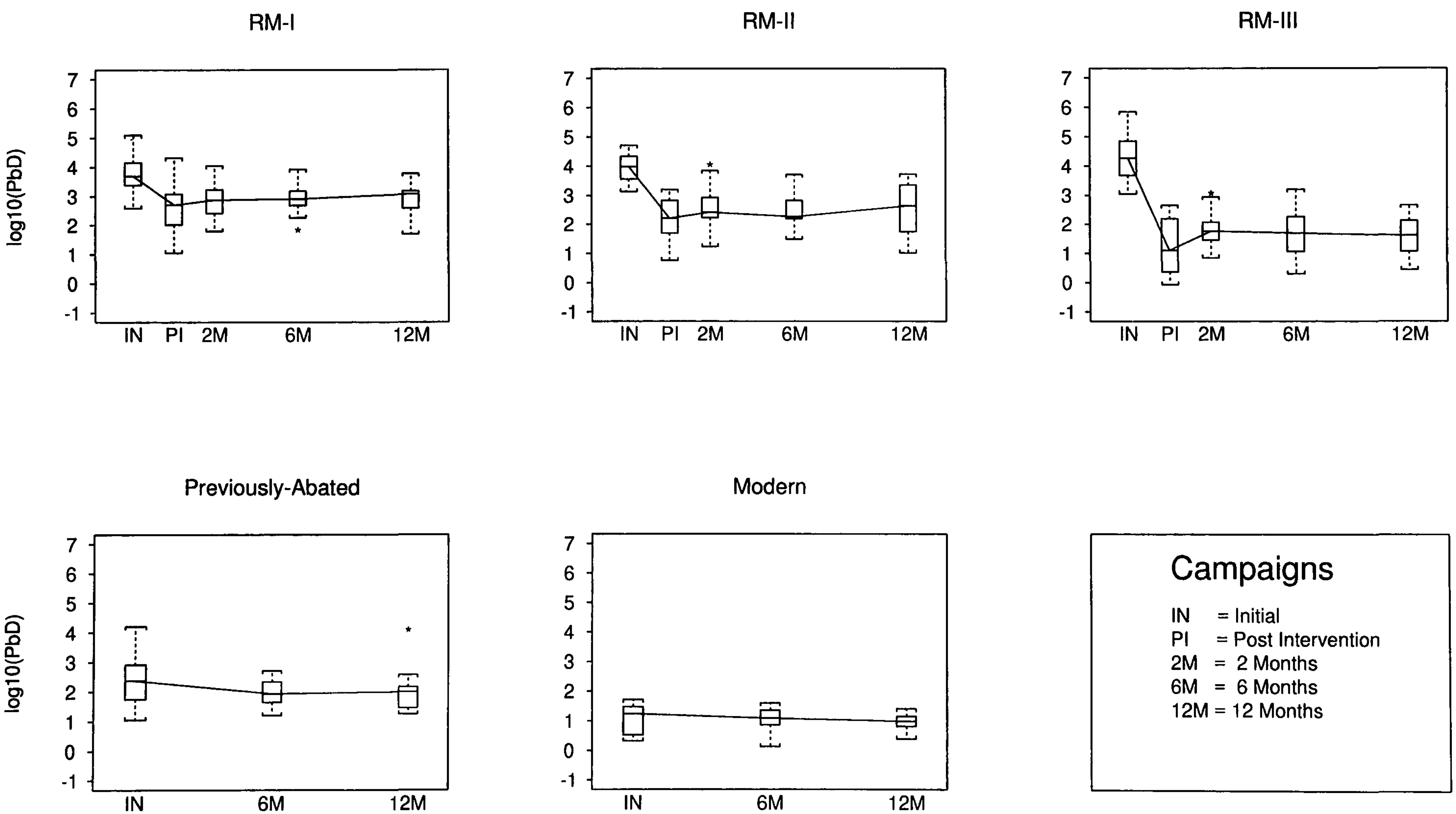


Figure 3 Dust Lead Loadings (PbD in ug/ft^2) across Campaigns for Window Well Surfaces

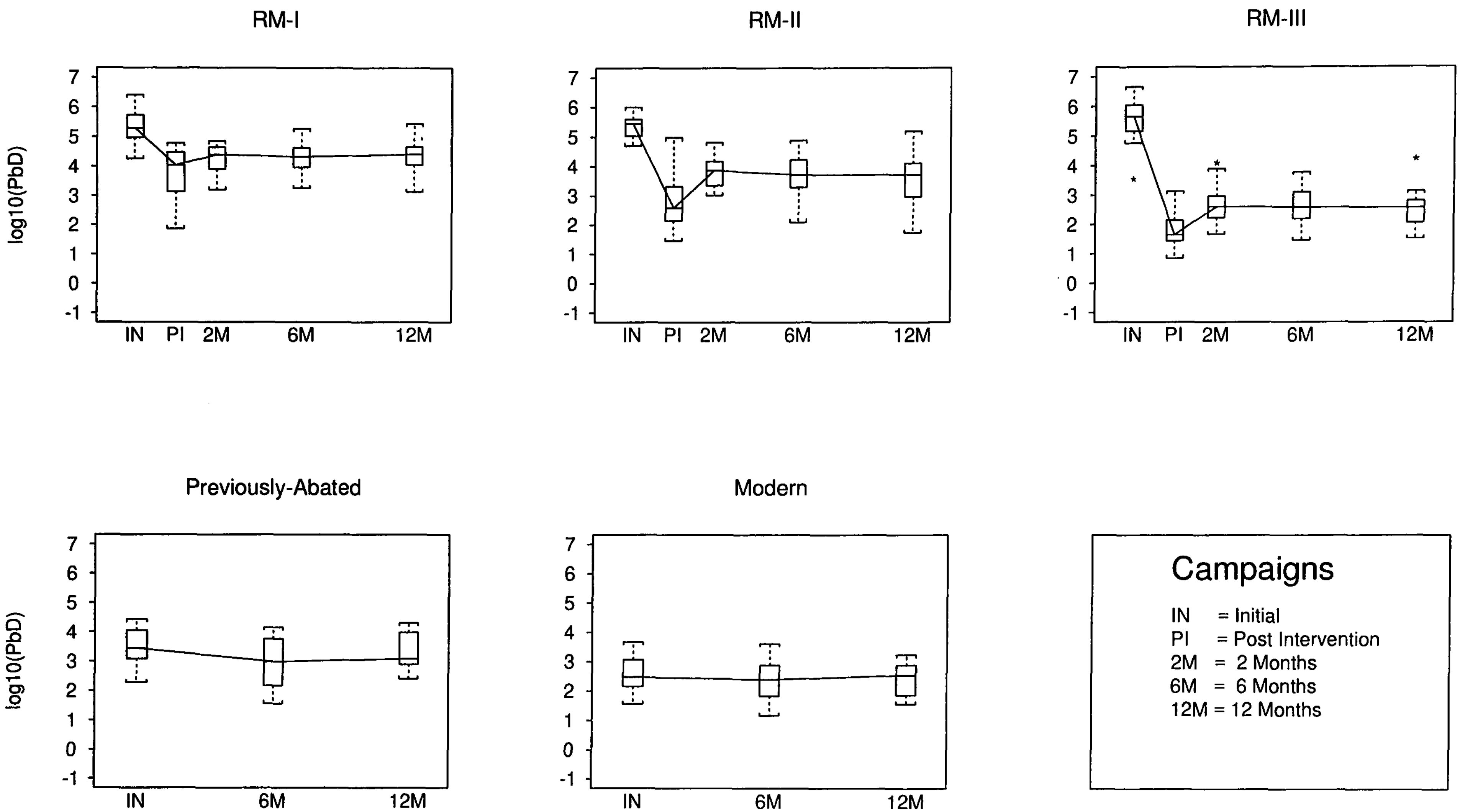


Figure 4 Dust Lead Loadings (PbD in ug/ft^2) across Campaigns for Interior Entryway Surfaces

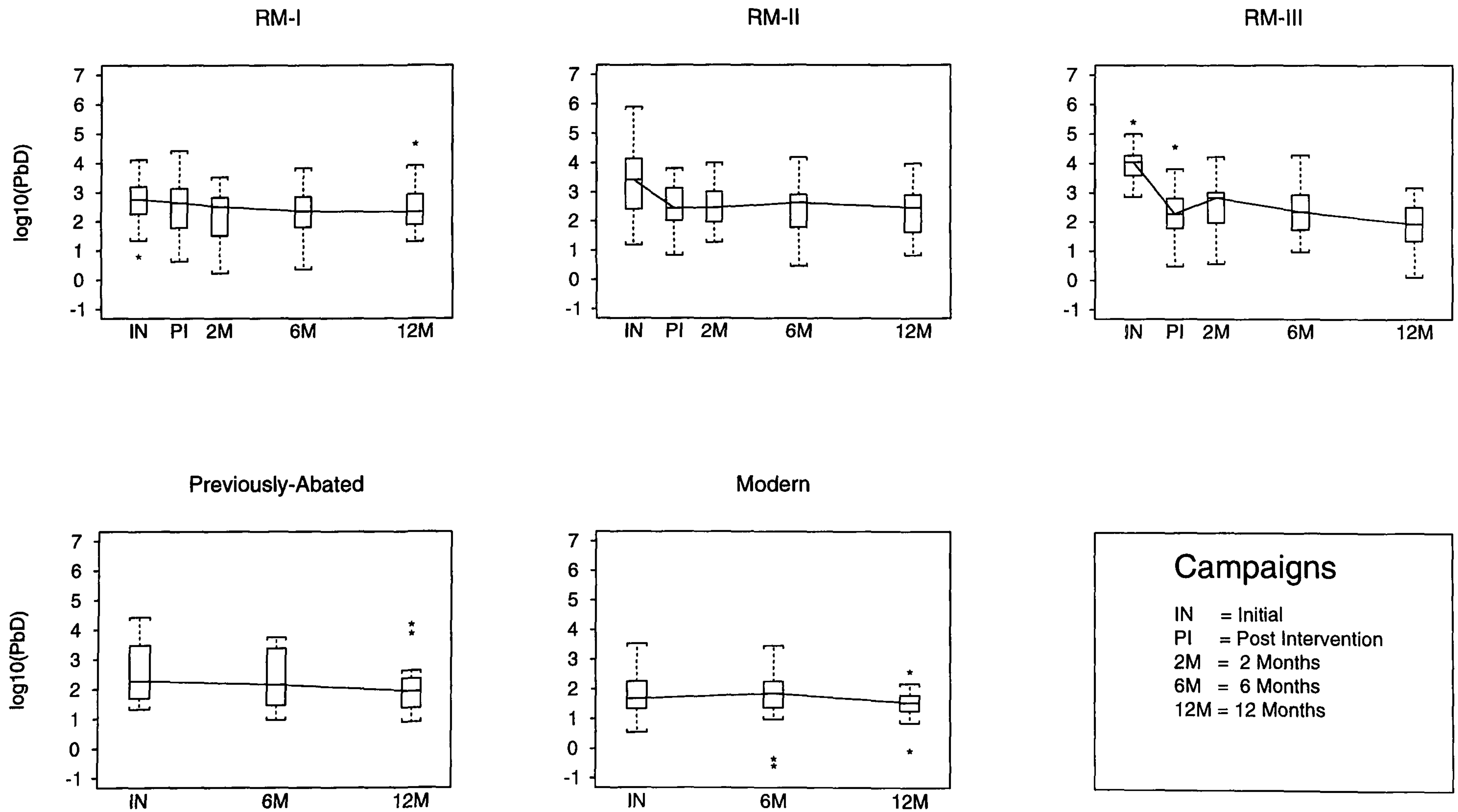


Figure 5 Dust Lead Concentrations (PbD-C in ug/g) across Campaigns for Floor Surfaces

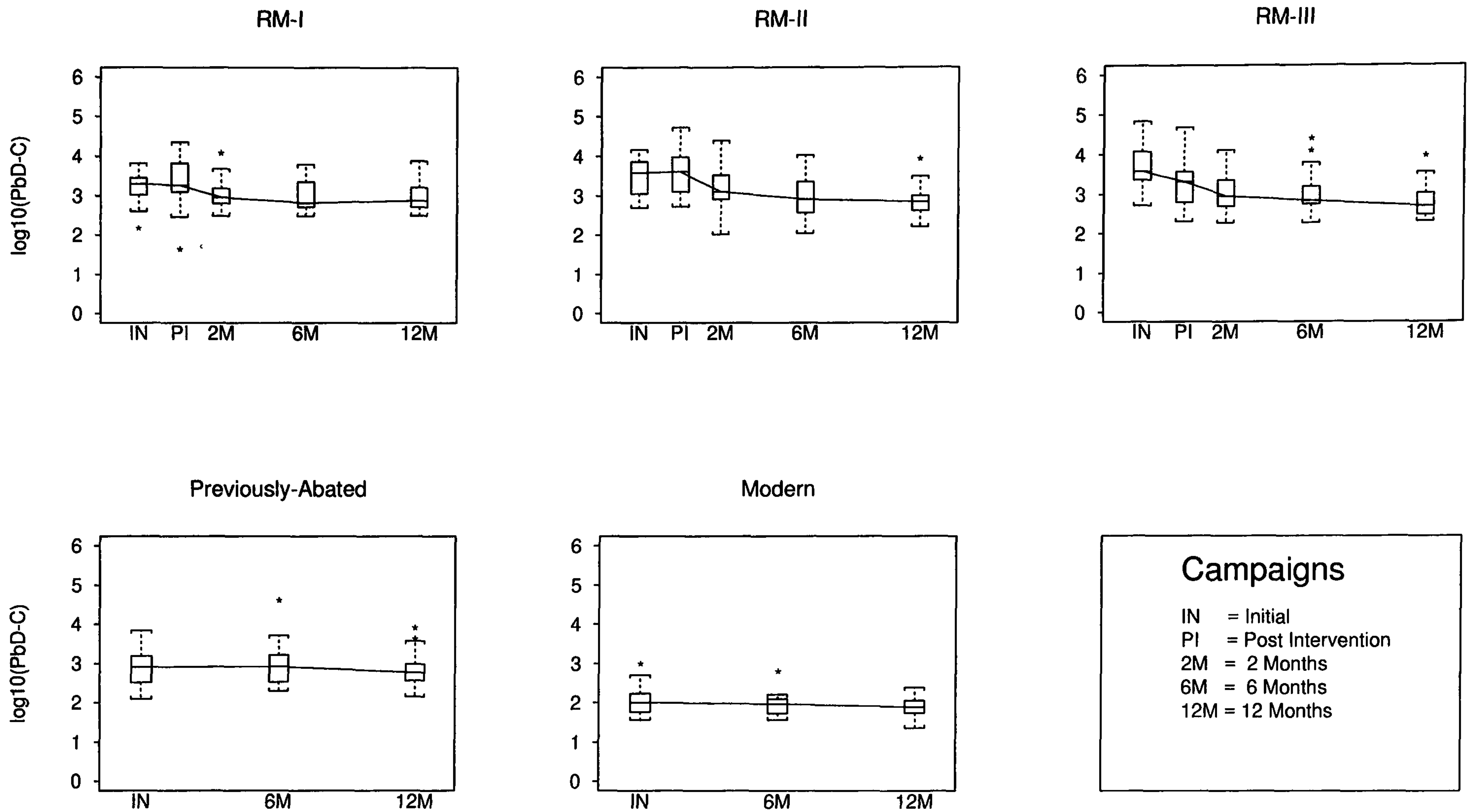


Figure 6 Dust Lead Concentrations (PbD-C in ug/g) across Campaigns for Window Sill Surfaces

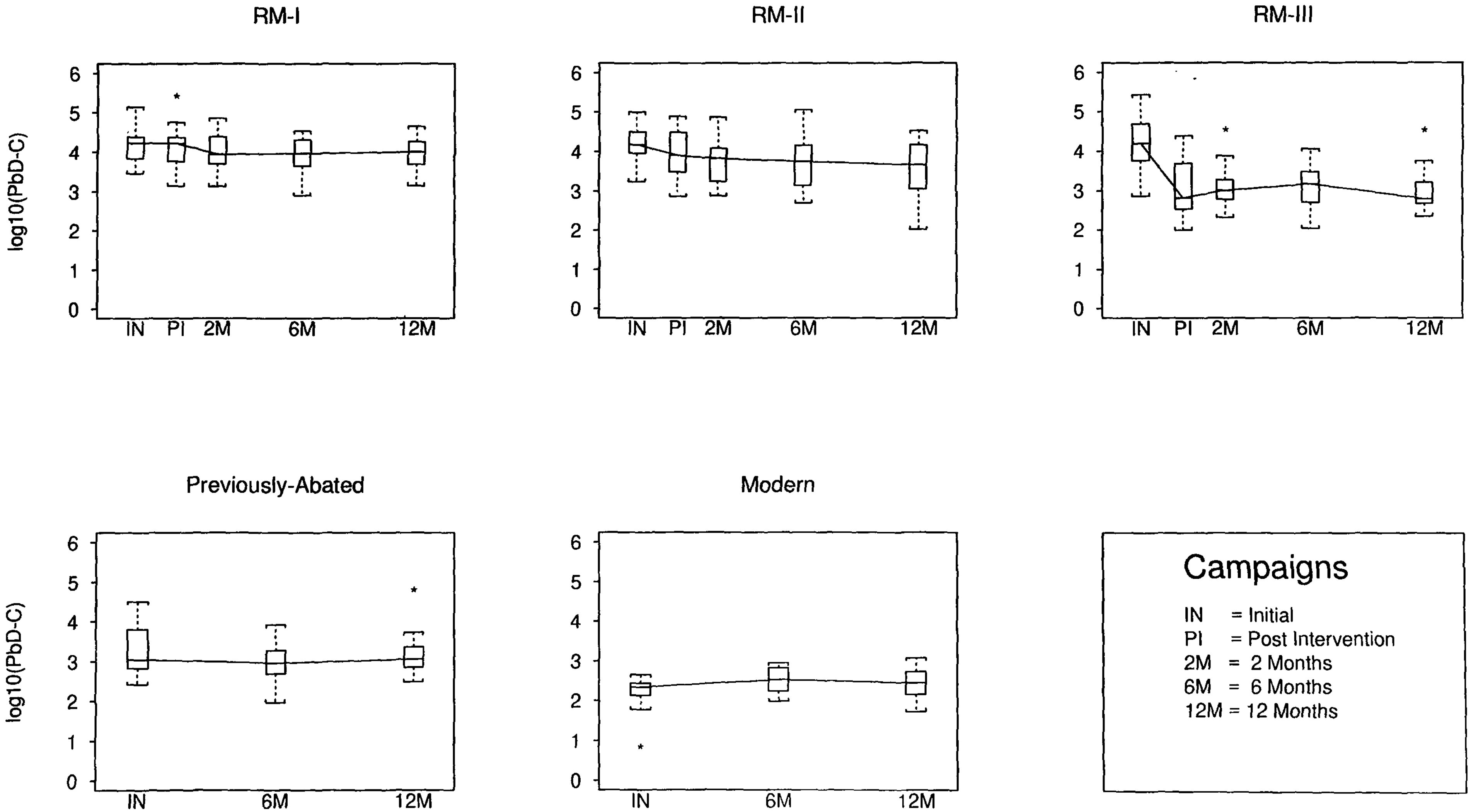


Figure 7 Dust Lead Concentrations (PbD-C in ug/g) across Campaigns for Window Well Surfaces

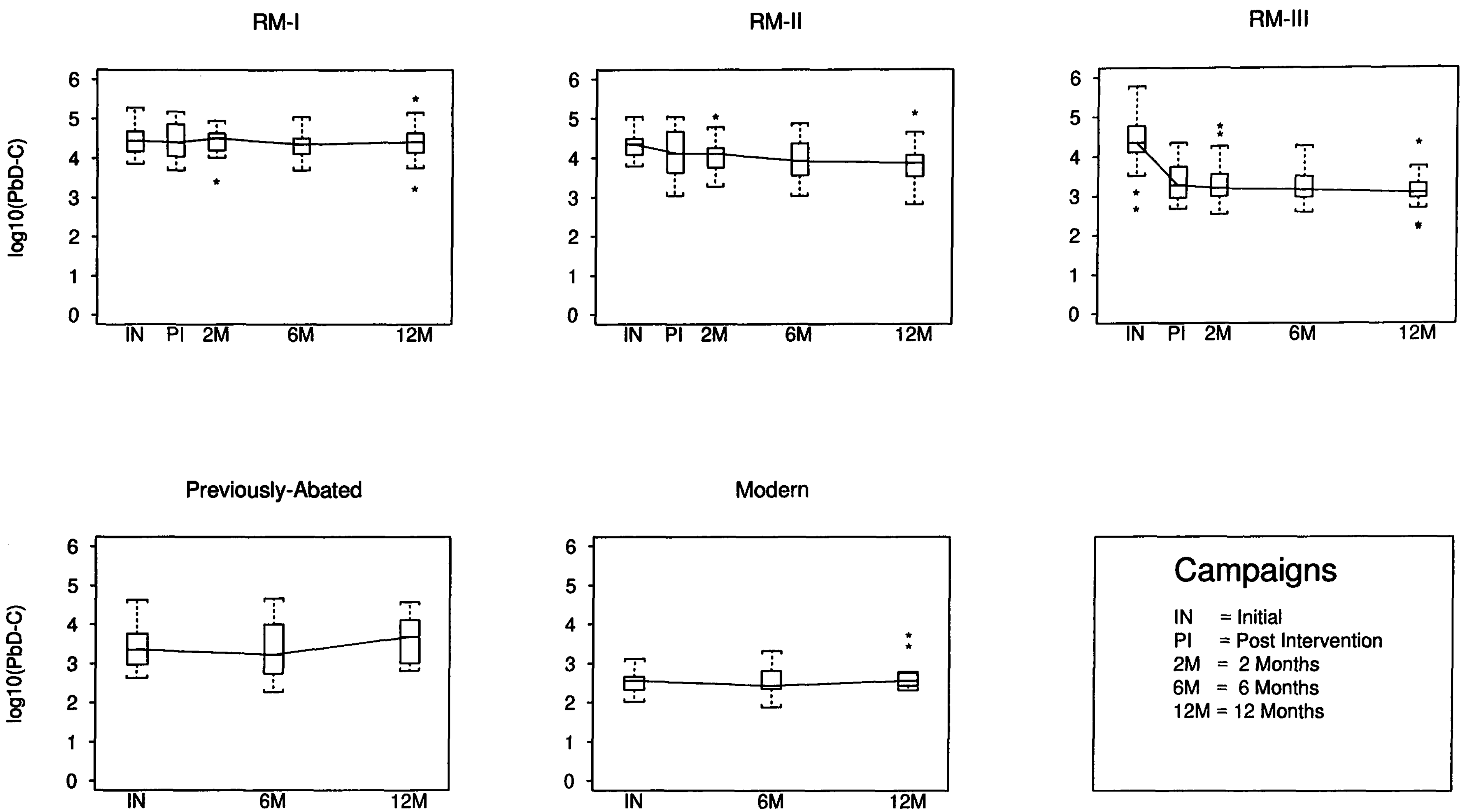


Figure 8 Dust Lead Concentrations (PbD-C in ug/g) across Campaigns for Interior Entryway Surfaces

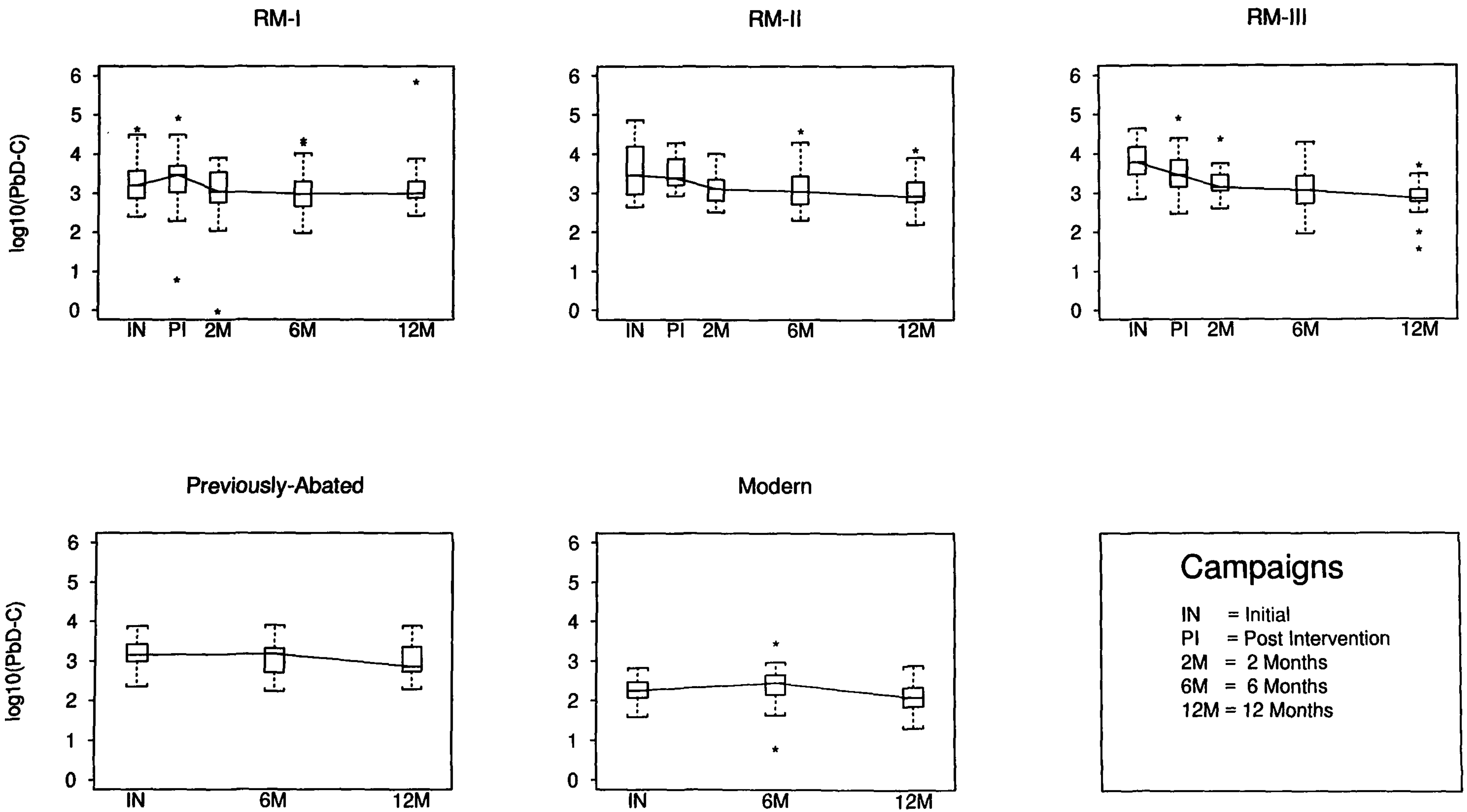


Figure 9 Dust Loadings (DL in mg/ft^2) across Campaigns for Floor Surfaces

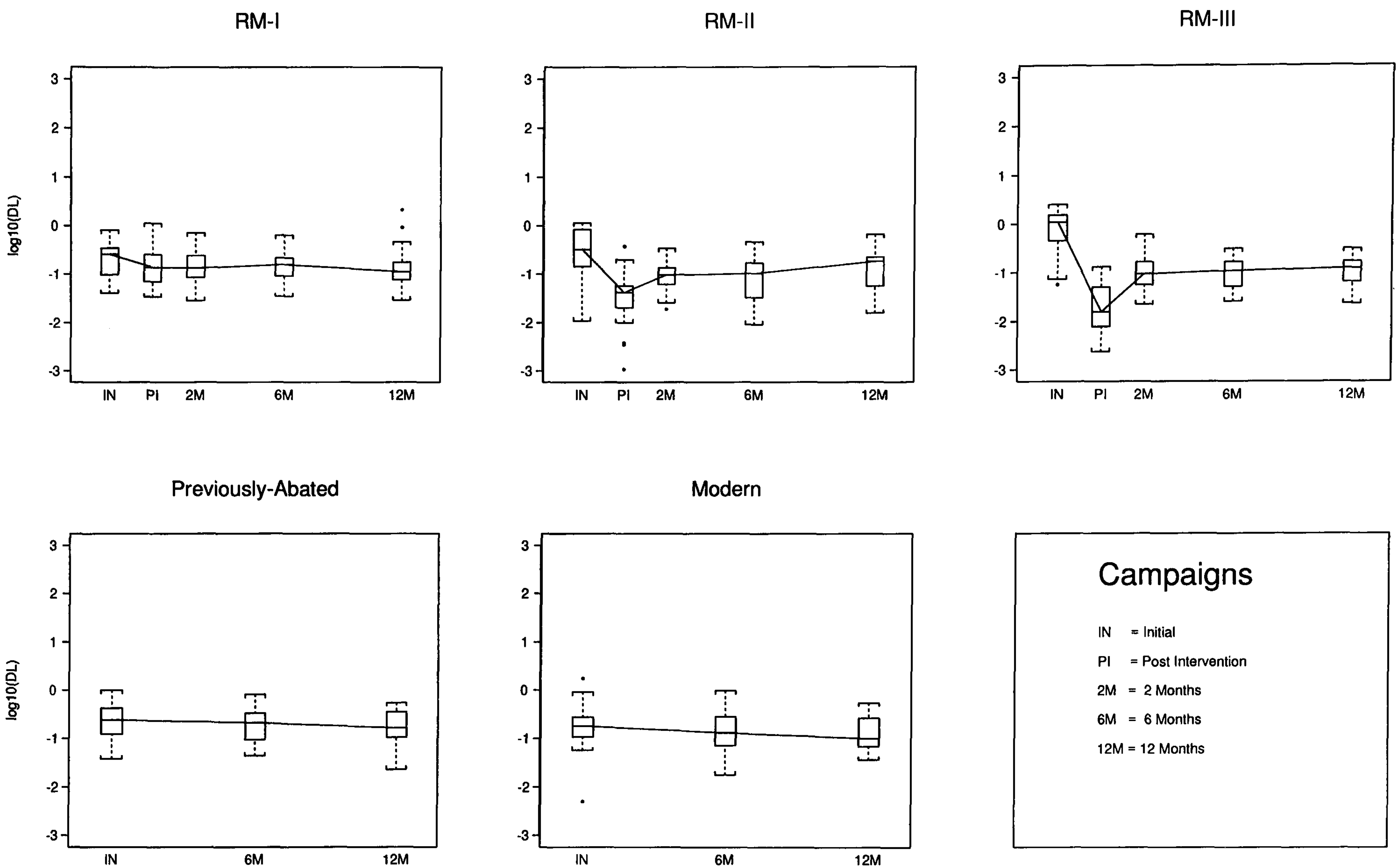


Figure 10 Dust Loadings (DL in mg/ft^2) across Campaigns for Window Sill Surfaces

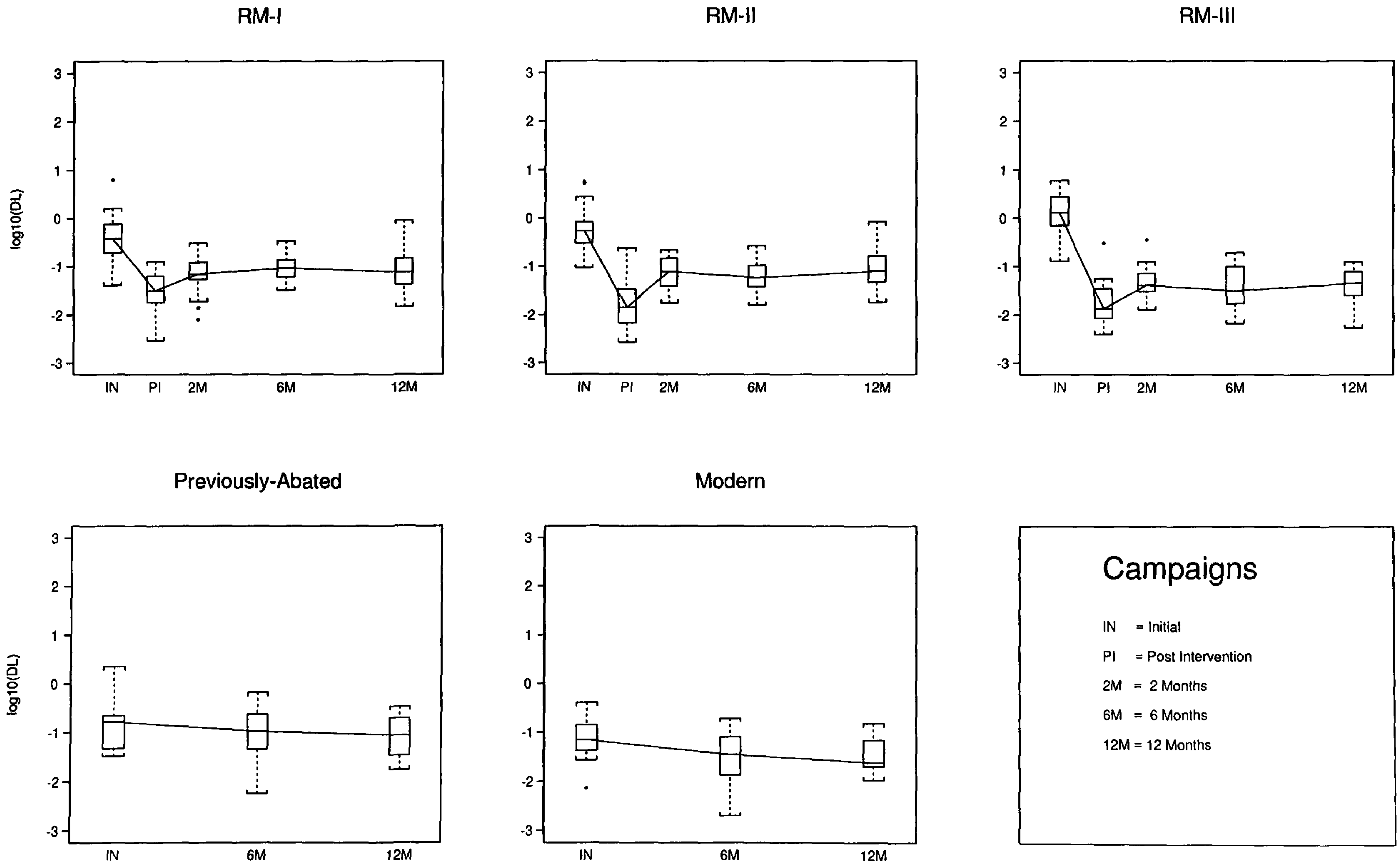


Figure 11 Dust Loadings (DL in mg/ft^2) across Campaigns for Window Well Surfaces

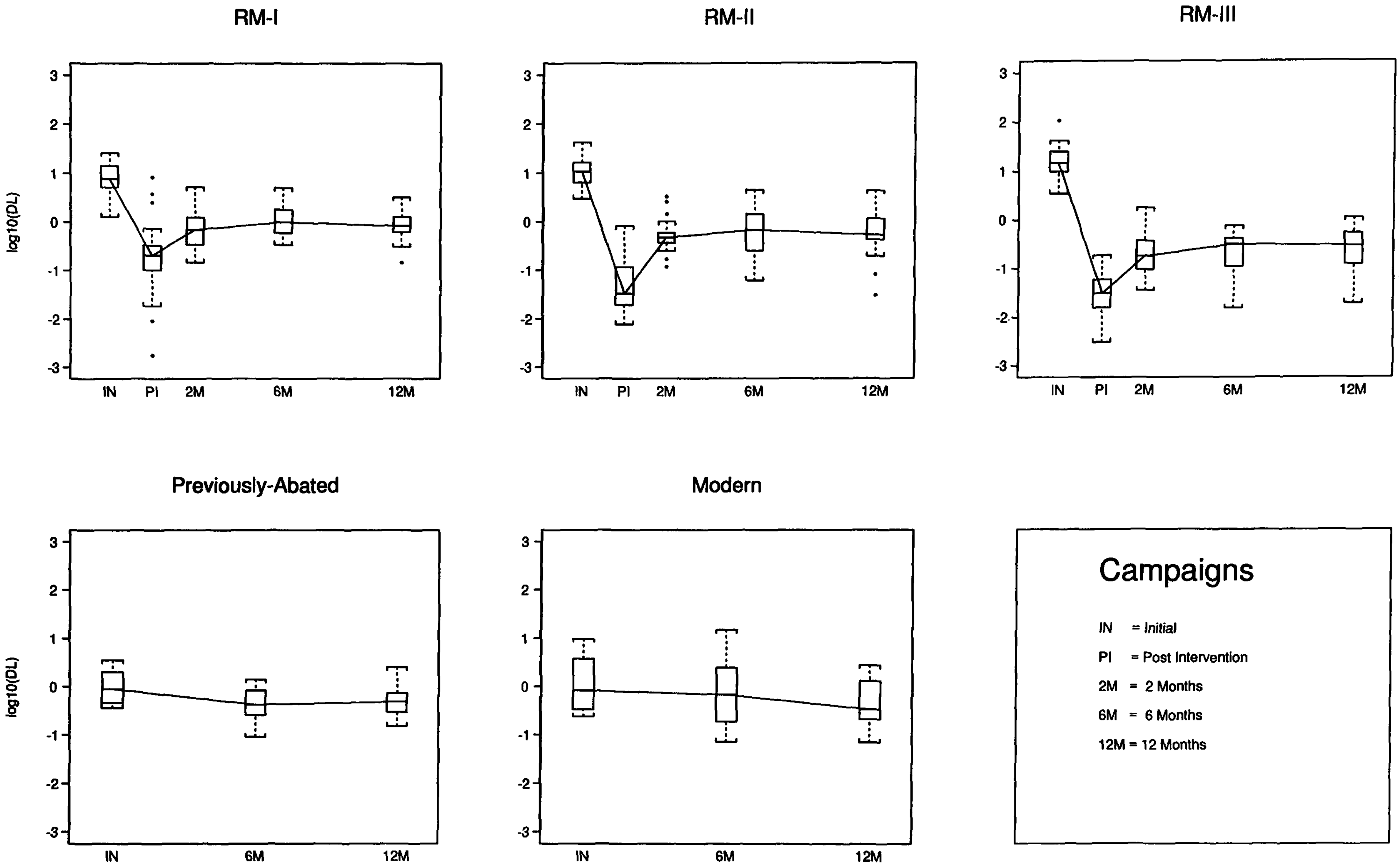


Figure 12 Dust Loadings (DL in mg/ft^2) across Campaigns for Interior Entryway Surfaces

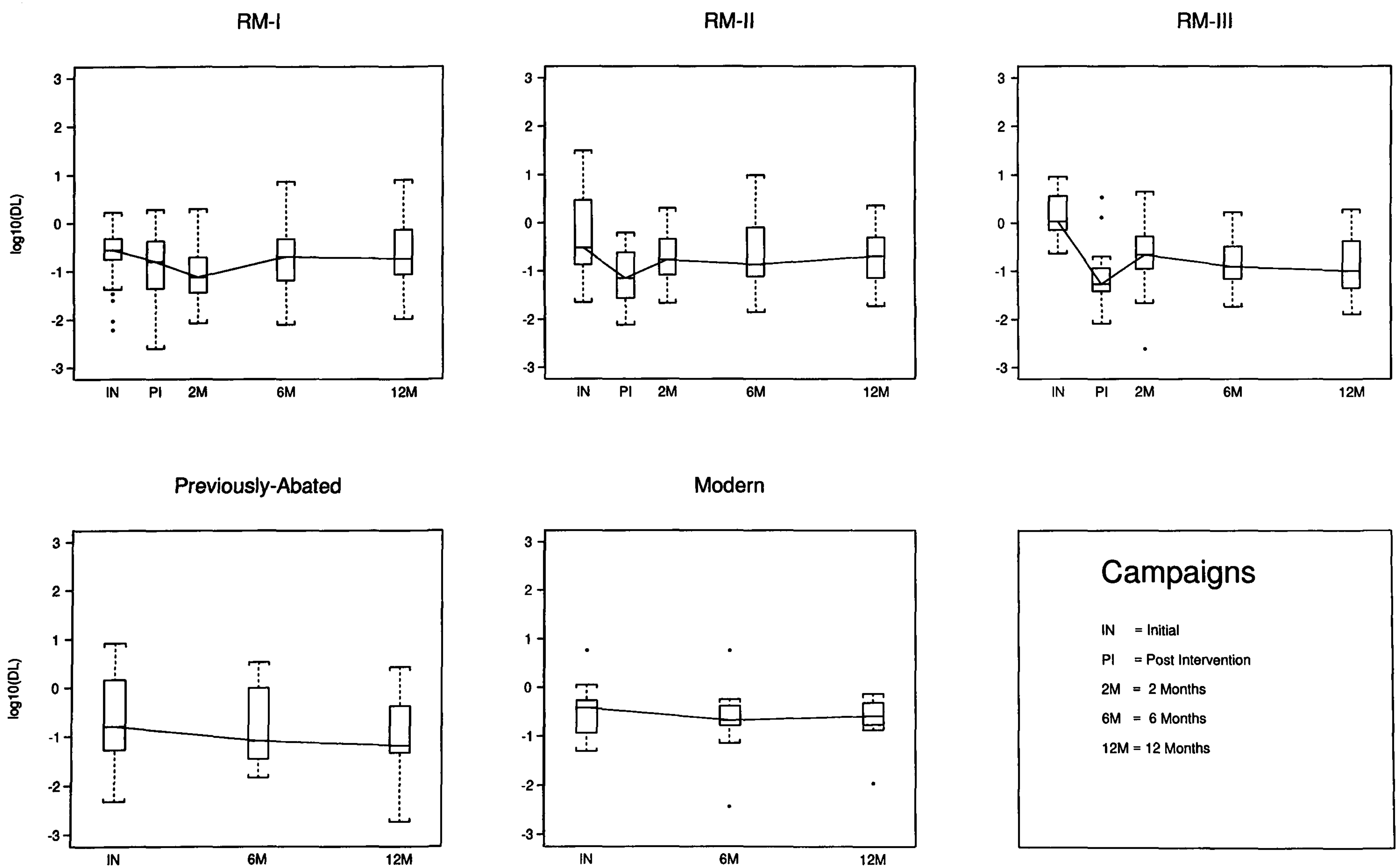


Figure 13 Blood Lead Concentrations (PbB in ug/dL) for Children with Initial Blood Pb < 20 ug/dL

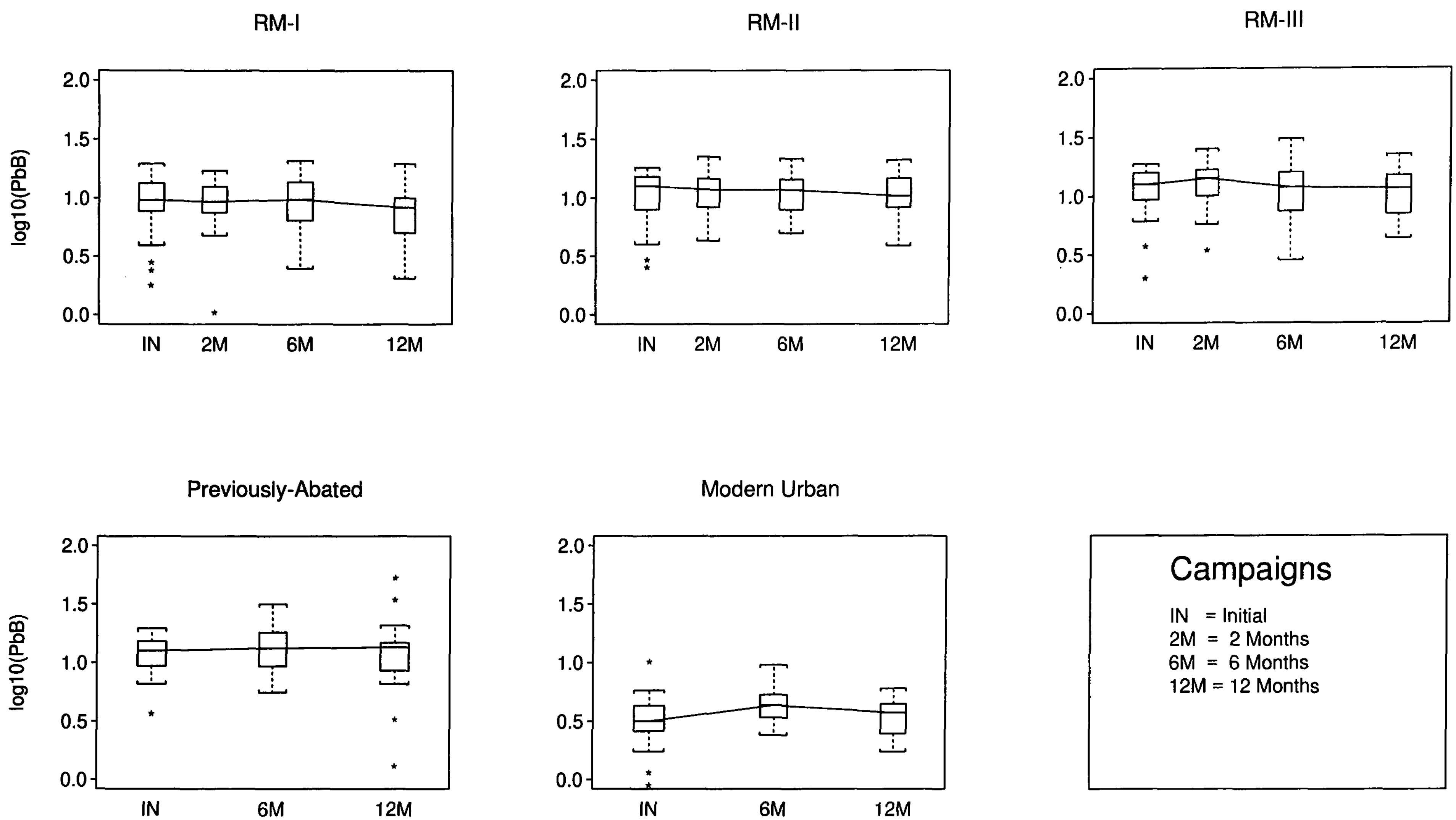


Figure 14: Repair & Maintenance Study - 12 Month Report
Children's Blood Lead Levels Across Time - R&M I Houses
Initial, 02, 06 and 12 month campaigns

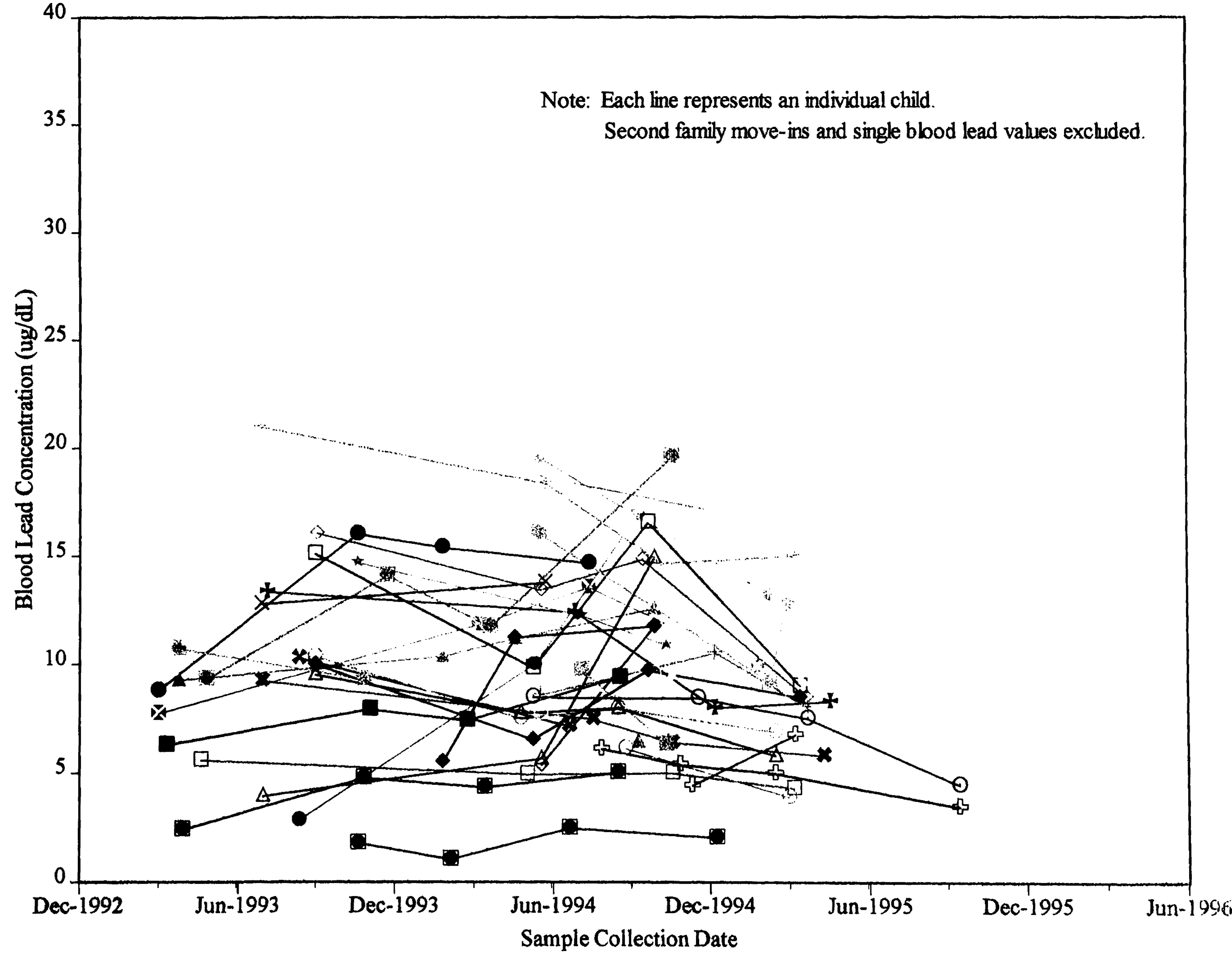


Figure 15: Repair & Maintenance Study - 12 Month Report
Children's Blood Lead Levels Across Time - R&M II Houses
Initial, 02, 06 and 12 month Campaigns

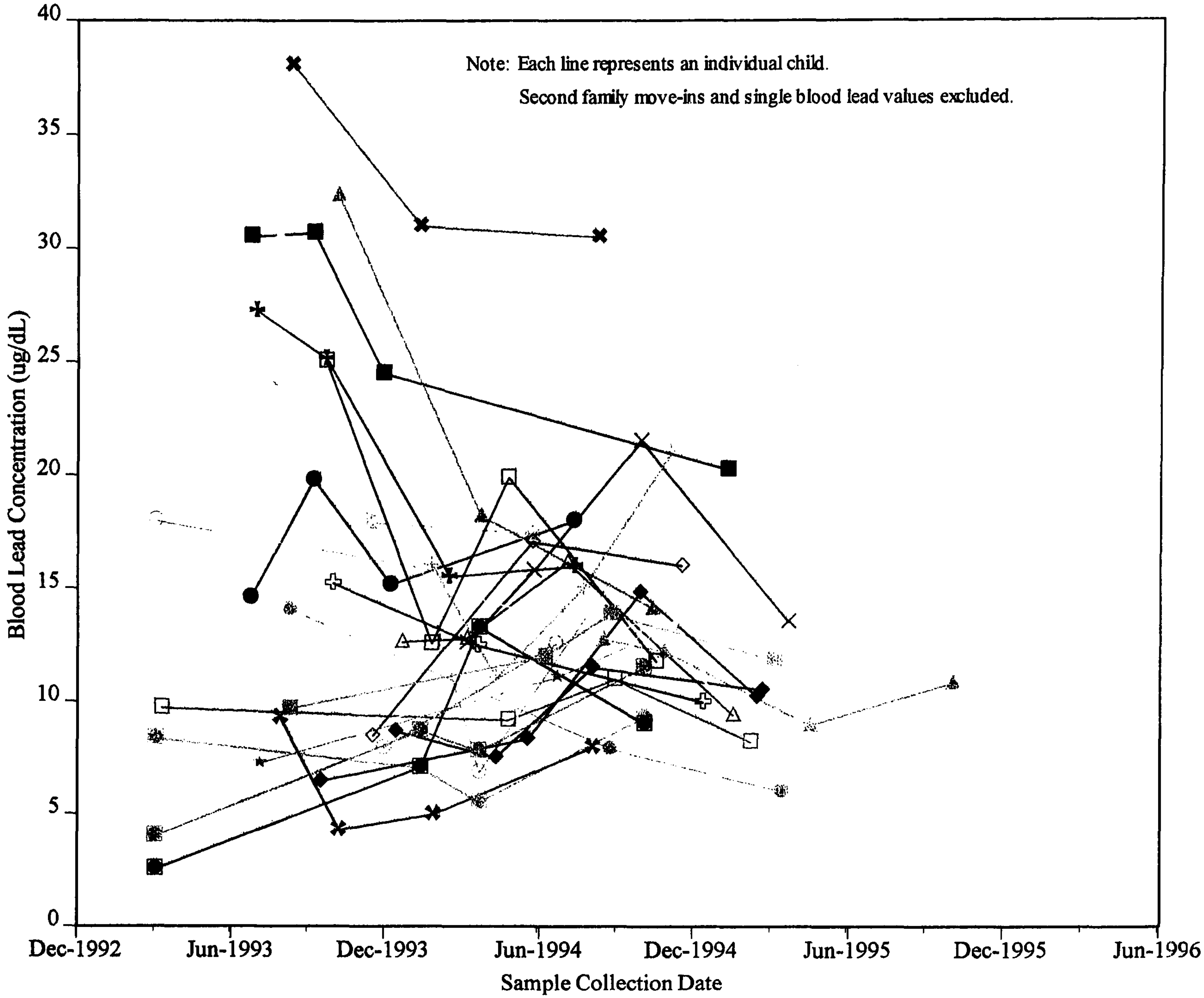


Figure 16: **Repair & MaintenanceStudy - 12 Month Report**

Children's Blood Lead Levels Across Time - R&M III Houses

Initial, 02, 06 and 12 month Campaigns

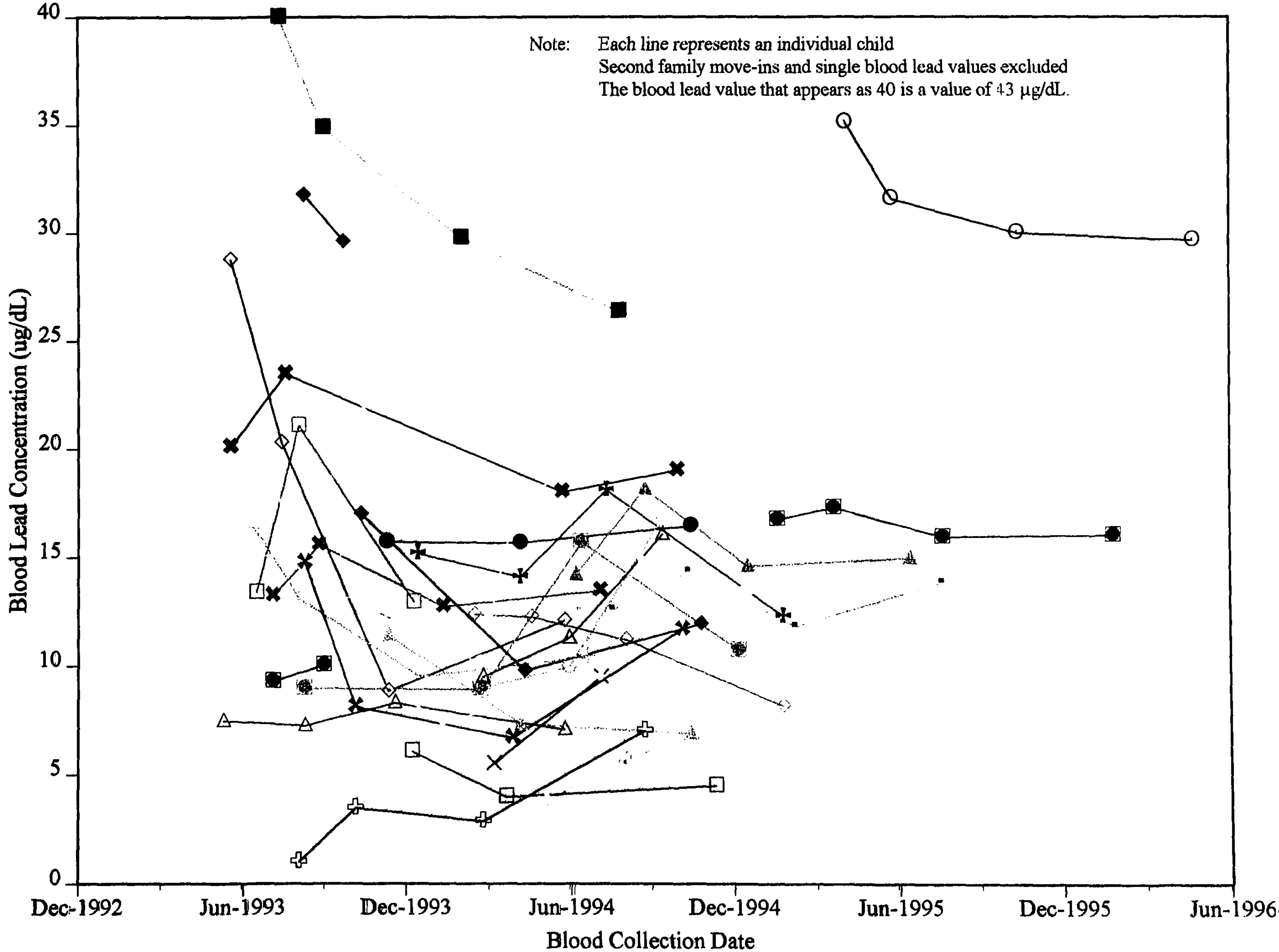


Figure 17: Repair & Maintenance Study - 12 Month Report
Children's Blood Lead Levels Across Time - Modern Urban Houses
Initial, 06 and 12 month Campaigns

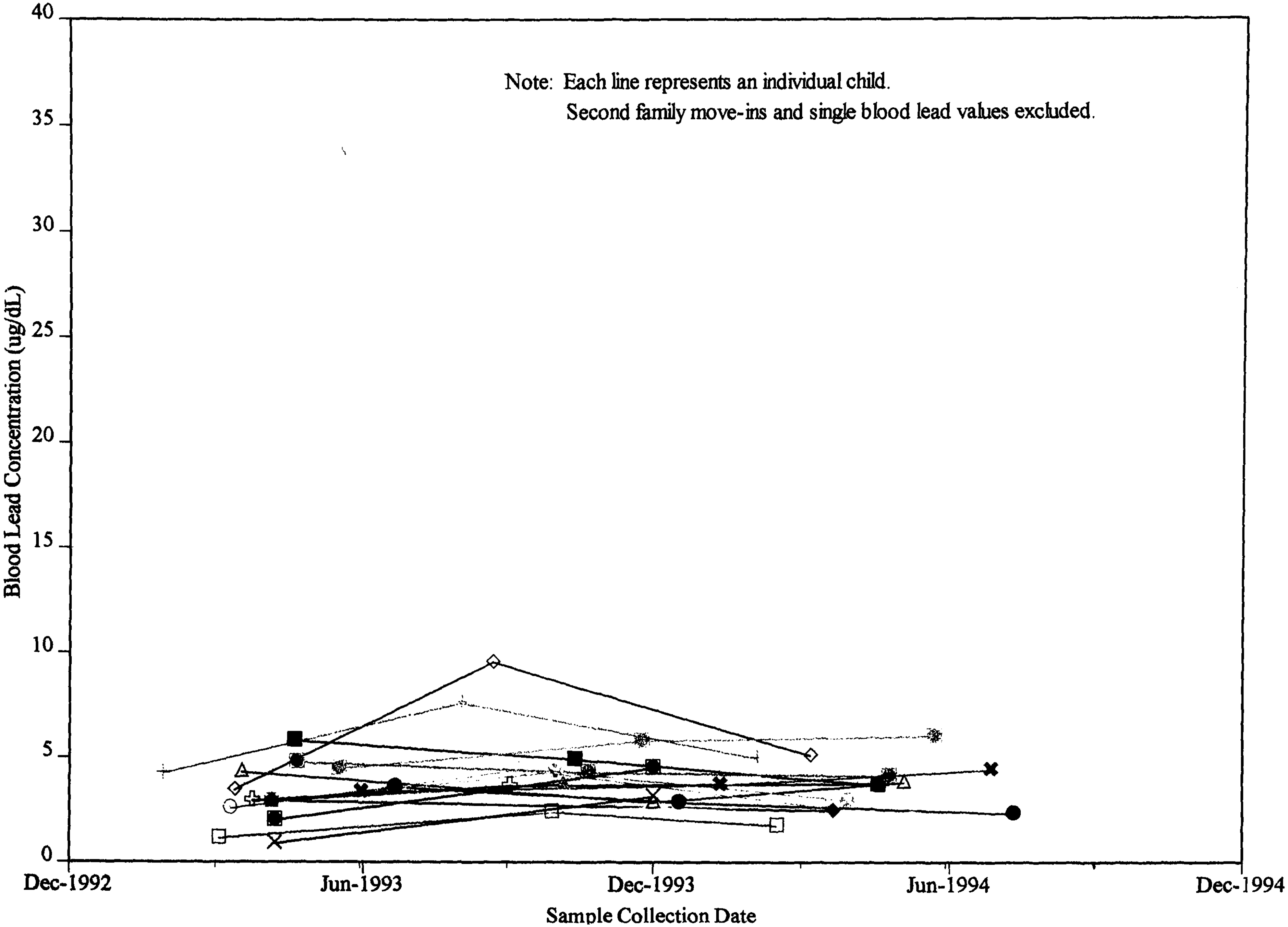


Figure 18: Repair & Maintenance Study - 12 Month Report
Children's Blood Lead Levels Across Time - Previously Abated Houses
Initial, 06 and 12 month Campaigns

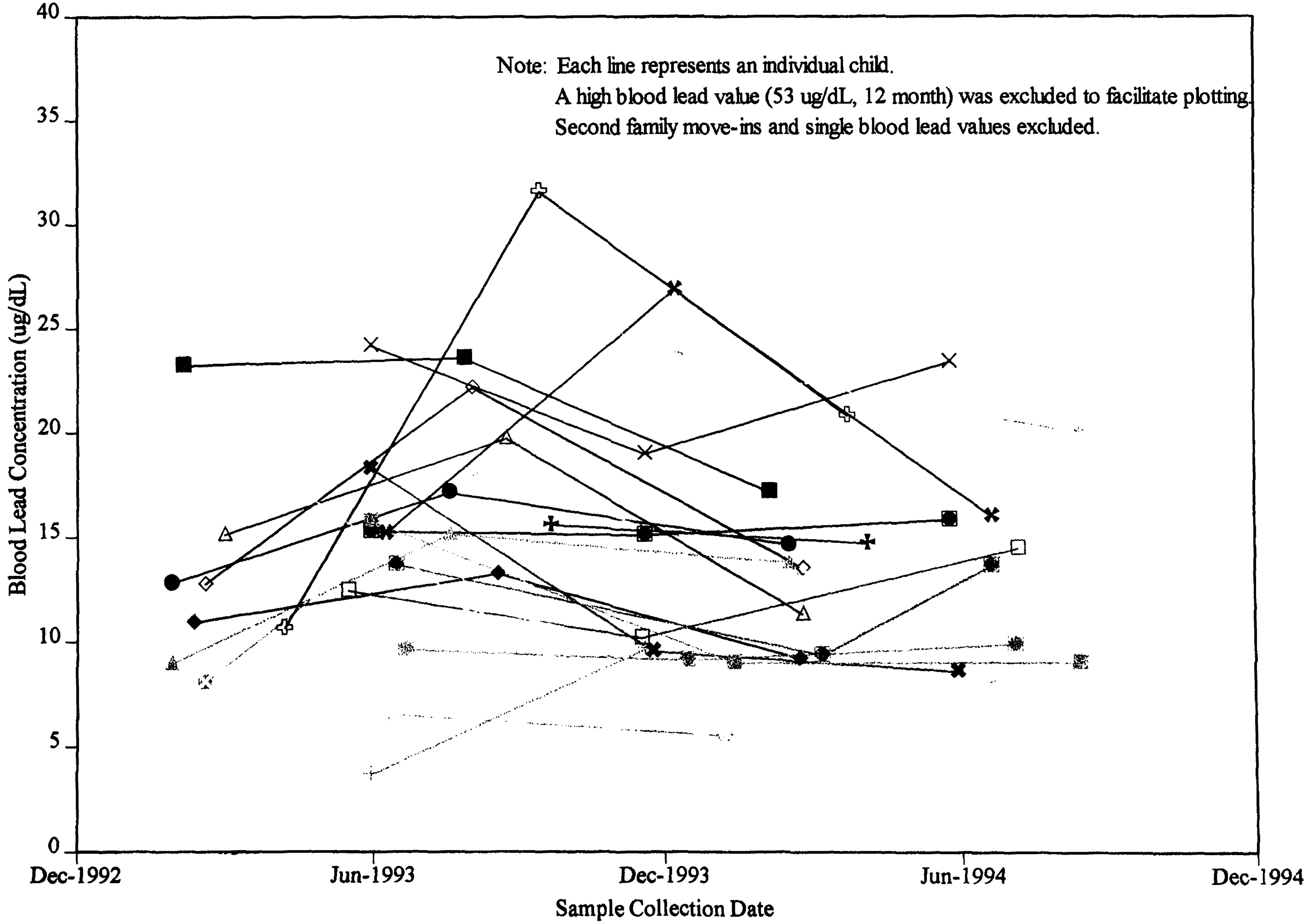


Figure 19: Geometric Mean Dust Lead Loadings By Surface Type And Study Group At The 12 Month Campaign

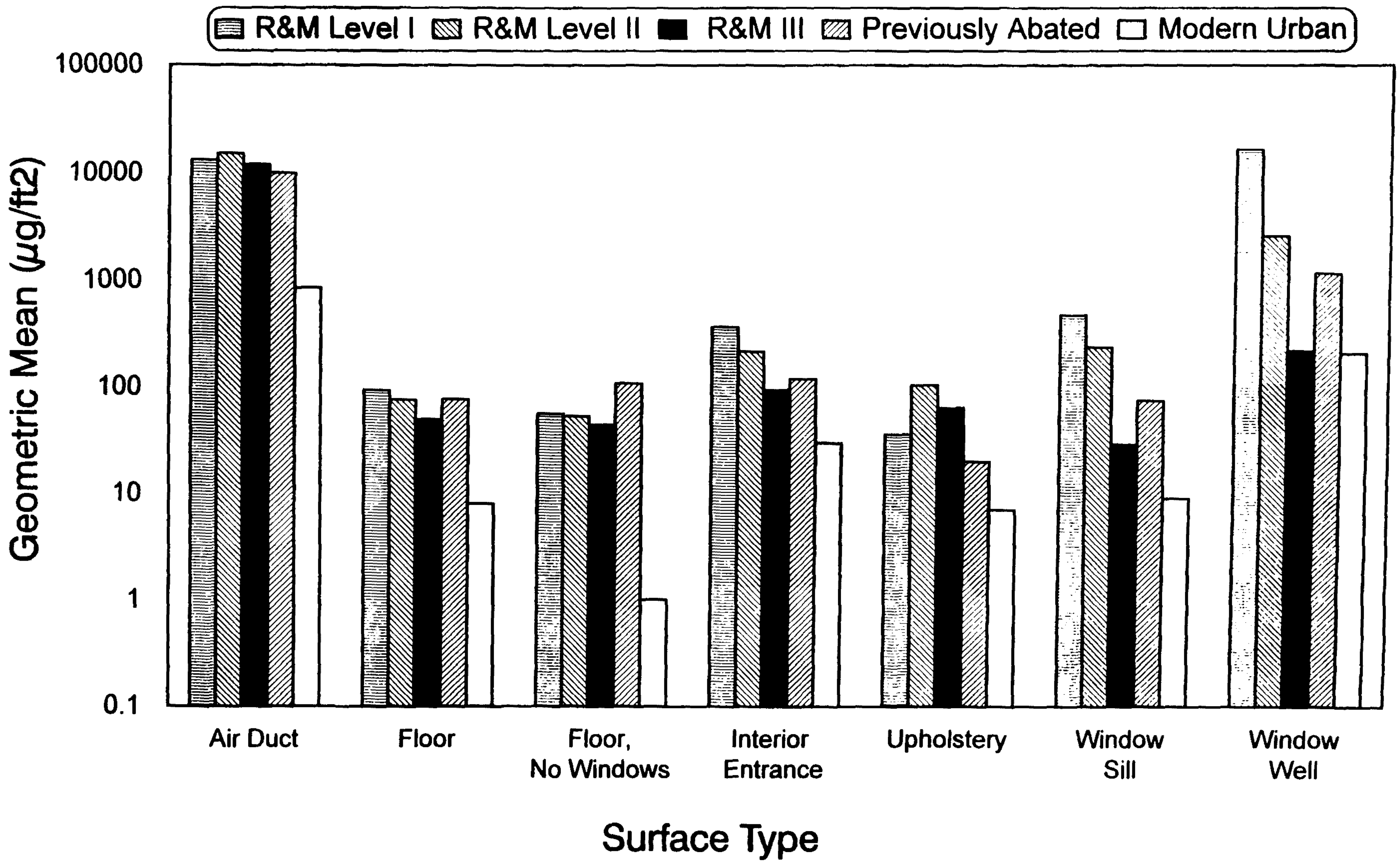


Figure 20: Geometric Mean Dust Lead Concentrations By Sample Type and Study Group At The 12 Month Campaign

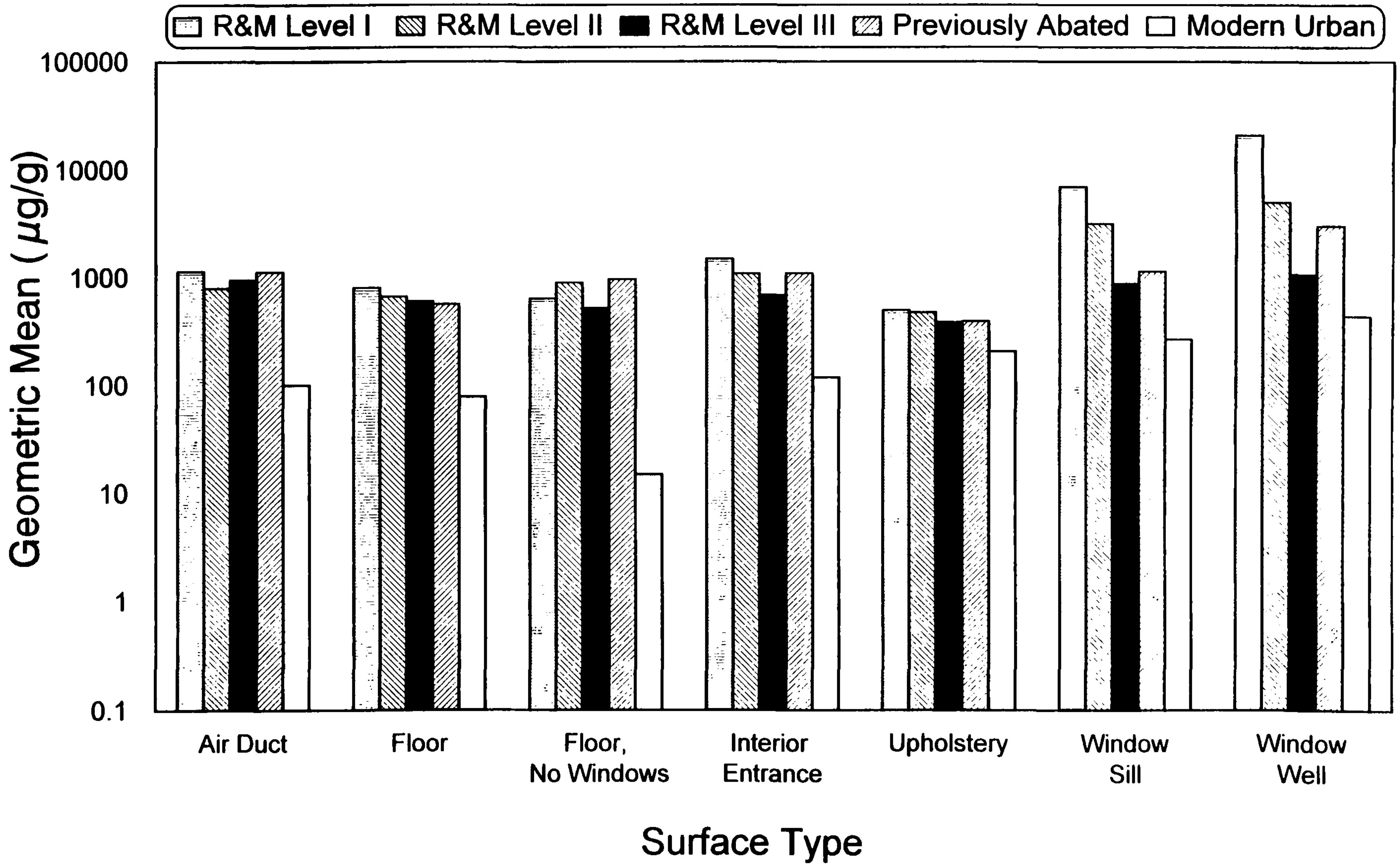
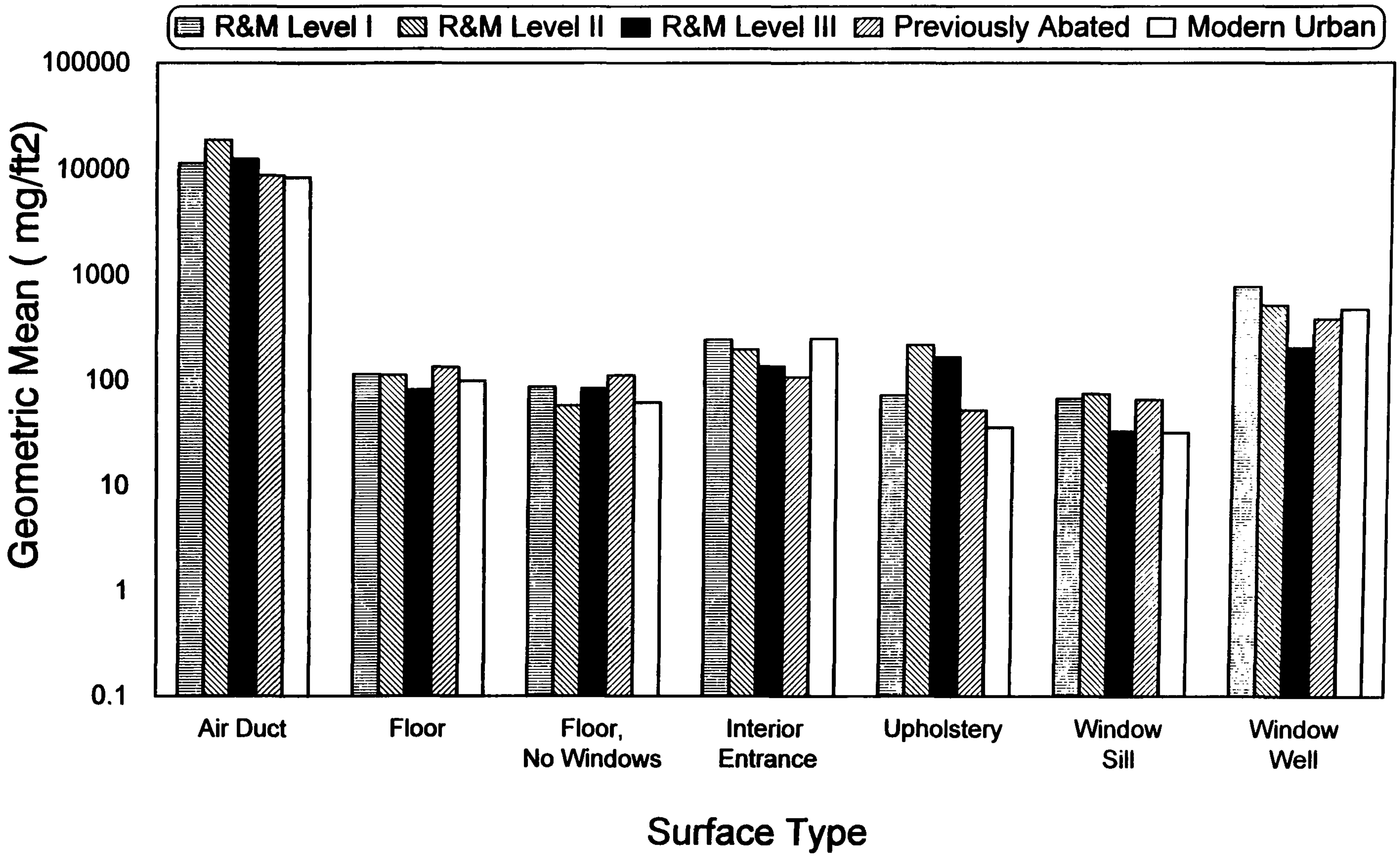


Figure 21: Geometric Mean Dust Loading By Sample Type and Study Group At The 12 Month Campaign



Figures 19-21 show that air ducts and window wells had the highest lead loadings and dust loadings among the various surfaces types across study groups. Lead concentrations tended to be highest for window wells and window sills.

Geometric mean lead loadings were ≤470 μg/ft² across groups and surface types at the 12-month campaign, except for air ducts in all groups and window wells in R&M I, R&M II and previously abated houses. Geometric mean air duct lead loadings ranged from 856 μg/ft² in modern urban houses to 15,237 μg/ft² in R&M II houses. For window wells, geometric mean lead loadings ranged from 208 μg/ft² in modern urban houses to 16,698 μg/ft² in R&M I houses. In R&M I houses, the geometric mean lead loadings were 94 μg/ft², 76 μg/ft² in R&M II houses, and 50 μg/ft² in R&M III houses for floors in rooms with windows. When measuring window sills, the geometric mean dust lead loadings were 470 μg/ft² for R&M I houses, 237 μg/ft² for R&M II houses, and 29 μg/ft² for R&M III houses. Geometric mean lead loadings for window wells were 16,698 μg/ft² in R&M I houses, 2,587 μg/ft² in R&M II houses, and 220 μg/ft² in R&M III houses.

Geometric mean dust lead concentrations across all groups and surface types at 12 months were <1,500 μg/g, except for window sills in R&M I houses, which were 6,964 μg/g, and 3,165 μg/g in R&M II houses, and window wells in R&M I houses (20,921 μg/g), R&M II houses (4,989 μg/g) and previously abated houses (3,031 μg/g). At 12 months, geometric mean dust loadings by group and by surface type were all <800 mg/ft², except for air ducts, which ranged from 8,474 to 19,000 mg/ft².

Modern urban houses continued to have the lowest lead loadings at the 12-month campaign. Geometric mean lead loadings were ≤30 μg/ft² across surface types, except for window wells (208 μg/ft²) and air ducts (856 μg/ft²). At 12 months, R&M I houses had statistically significantly higher geometric mean lead loadings for floors in room with windows (94 μg/ft²), for window sills (470 μg/ft²), and for window wells (16,698 μg/ft²), compared to R&M III houses (50 μg/ft² for floors in rooms with windows, 29 μg/ft² for window sills, and 220 μg/ft² for window wells). Geometric mean lead loadings in R&M II houses were intermediate (76, 237, and 2,587 μg/ft², respectively).

At 12 months, modern urban houses continued to have the lowest geometric mean lead concentrations across all surface types (<440 μg/g). The geometric mean lead concentrations for interior entryways and interior floors across the other four study groups were higher and were not statistically different from each other. R&M I houses had statistically higher geometric mean lead concentrations for window sills (6,964 μg/g) and for window wells (20,921 μg/g) compared to R&M III houses which had readings of 881 μg/g for window sills and 1,071 μg/g for window wells, and compared to R&M II houses which had intermediate lead concentrations of 3,165 μg/g for window sills and 4,989 μg/g for window wells.

The five groups of houses were most similar to each other in terms of dust loadings. As with the other measures, however, dust loadings tended to be highest in R&M I houses, lowest in R&M III houses, and intermediate in R&M II houses. For windows wells, R&M I houses had a statistically higher geometric mean dust loading (777 mg/ft^2) than R&M III houses (205 mg/ft^2). R&M II houses had intermediate dust loadings (519 mg/ft^2).

Summary Measures Of Dust Data For A House

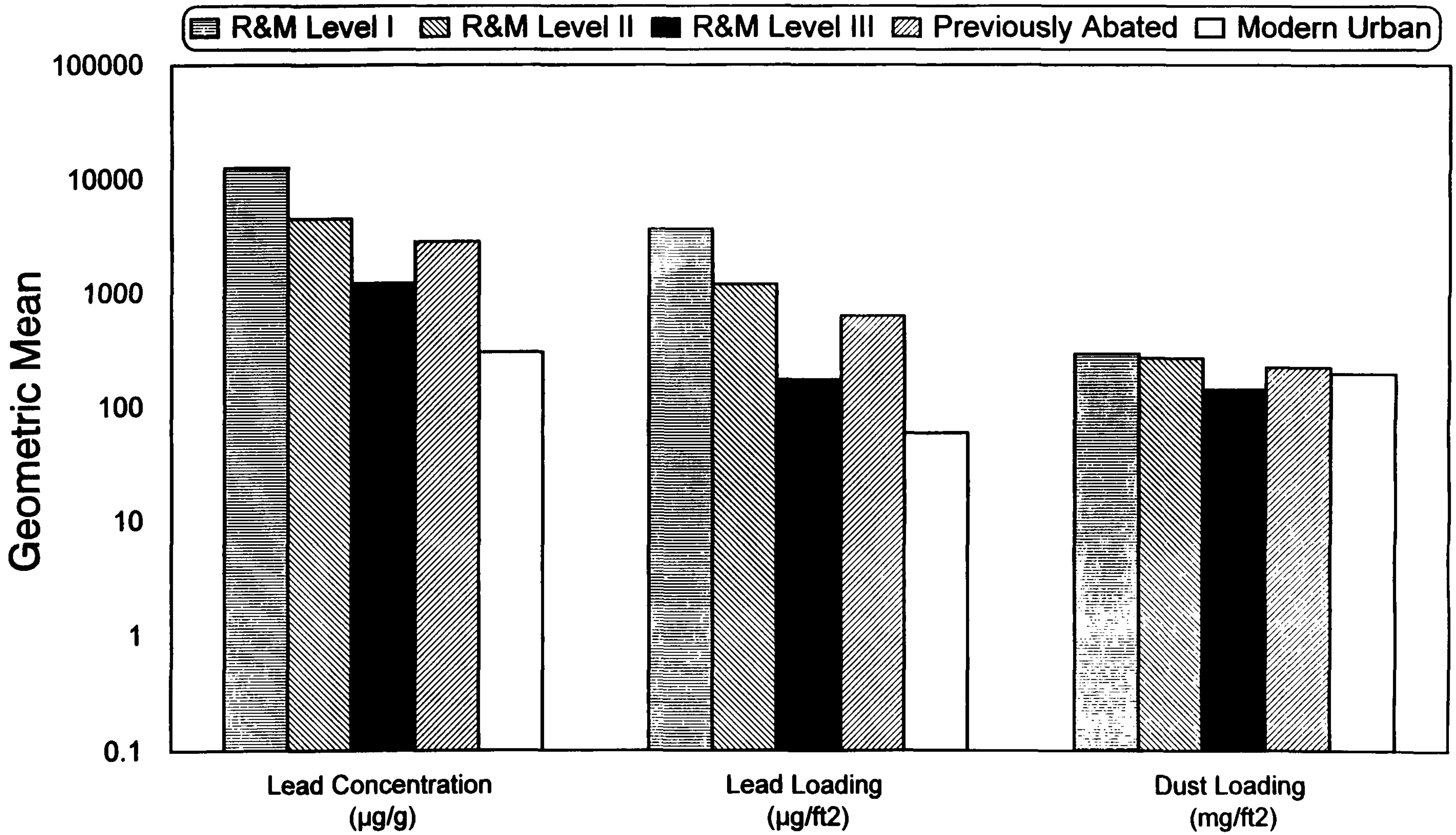
Summary measures of dust data for each house were calculated based on the weighted average of the measurements from surface types common to all campaigns. Lead loadings and dust loadings were weighted by the surface area sampled. Lead concentrations were weighted by the sample mass. The "weighted average loading" within each house was calculated as the total mass of lead collected divided by the total area sampled (or total dust mass, depending on the dust endpoint). These weighted averages were computed based on samples collected from floors in rooms with windows, window sills, and window wells. The results were then transformed using the natural logarithm.

Figure 22 displays the geometric mean of the weighted averages for each dust endpoint at the 12-month campaign for each group. Based on these summary measures, geometric mean lead loadings at the 12-month campaign were approximately 21 times higher in R&M I houses than in R&M III houses. This difference is due to the order of magnitude higher lead concentrations and approximately two-fold higher dust loadings in R&M I houses, relative to R&M III houses. Lead concentrations and lead loadings in the modern urban and previously abated houses were one to two orders of magnitude lower than corresponding levels in the intervention groups. The five study groups were most similar in terms of weighted average dust loadings.

Paint Chips On Sampled Window Surfaces And Window Surface Conditions

For each sub-area included in a composite dust sample from window sills and window wells, field staff noted the presence or absence of paint chips and rated the surface condition (smooth and intact to rough and deteriorated). At 12 months, observations of the presence of paint chips on window sills and window wells were reduced for all three R&M groups relative to pre-intervention. The decline was greatest in R&M III houses, intermediate in R&M II houses, and lowest in R&M I houses. Similarly, 12-month observations of surface conditions for window sills and window wells showed improvement over pre-intervention observations for all R&M groups. The improvement was greatest in R&M III houses and intermediate in R&M II houses for window sills, and similar in all three groups for window wells.

Figure 22: Overall Weighted Geometric Mean Lead Concentrations, Lead Loading, And Dust Loading By Study Group At The Twelve Month Campaign



Summary measures are based on weighted averages of all dust sample types within houses

Lead In Drip-Line Soil

Drip-line soil samples were not collected at the 12-month campaign. Therefore, this report provides data on soil lead concentrations at the six-month campaign for each study group (Table 17). These data are limited due to the lack of soil for most study houses. Soil lead concentrations in the modern urban houses at six months (geometric mean 73 μg/g, range 34 to 229 μg/g) remained similar to their corresponding levels at the initial campaign (geometric mean 63 μg/g, range 29 to 154 μg/g). Across previously abated and R&M houses, individual soil sample values ranged from 182 to 7,845 μg/g at six months. A similar range of readings were obtained at the initial campaign (range of 233 to 15,968 μg/g).

Lead In Drinking Water

Drinking water samples were not collected at the 12-month campaign. Water lead concentrations at six months were unchanged from their geometric mean baseline level of ≤4 μg/L (ppb) across all groups. The range of values also remained the same across time (less than the instrumental limit of detection (<LOQ) to 44 μg/L) (Table 18).

Correlations Among Dust Lead Measurements Across Surface Types

Statistically significant ($p<.05$) correlations were found for dust lead loadings and concentrations between most surfaces types at the 12-month campaign (Tables 19 and 20). The highest correlation coefficients for these measures were observed between window sills and window wells ($r=.67$ for lead loadings and $r=.61$ for lead concentrations) and between air ducts and floors in rooms with windows ($r=.62$ for lead loadings). Fewer statistically significant correlations were found between surface types for dust loadings (Table 21).

Correlation Between Blood Lead And Dust Lead

Using blood lead concentration for the youngest child in each house at 12 months, statistically significant correlations were found between ln(children's blood lead) and ln(dust lead loadings) for floors in rooms with windows ($r=.35$), floors in rooms without windows ($r=.31$), upholstery ($r=.42$) and air ducts ($r=.35$) (Table 22). The Pearson correlation coefficients for the association between ln(blood lead) and ln(dust lead concentration) were statistically significant for floors in rooms with windows ($r=.44$), floors in rooms without windows ($r=.32$), upholstery ($r=.40$), air ducts ($r=.38$), and interior entryways ($r=.28$) (Table 22). Dust loadings were not significantly correlated with children's blood lead concentrations for any surface. Similar patterns of correlations were found when blood lead concentrations of all children in a household were considered (unadjusted for clustering) (Table 23).

Table 17: Descriptive Statistics For Soil Lead Concentrations By Study Group At The Six-Month Campaign

Study Group	n	Minimum (μg/g)	Maximum (μg/g)	Geometric Mean (μg/g)	S.D. on log scale	Lower 95% CI for GM (μg/g)	Upper 95% CI for GM (μg/g)
R&M I	12	182	4,530	689	0.915	385	1,232
R&M II	14	216	2,608	706	0.732	463	1,078
R&M III	8	369	2,267	736	0.649	428	1,267
Previously Abated	3	304	7,845	1,521	1.625	27	86,150
Modern Urban	13	34	229	73	0.489	54	98

Table 18: Descriptive Statistics For Water Lead Concentrations By Study Group At The Six-Month Campaign

Study Group	n	Minimum (μg/L)	Maximum (μg/L)	Geometric Mean (μg/L)	S.D. on log scale	Lower 95% CI for GM (μg/L)	Upper 95% CI for GM (μg/L)
R&M I	25	<LOD[a]	11	2	1.132	1	3
R&M II	23	<LOD[a]	17	3	1.184	2	5
R&M III	26	<LOD[a]	62	2	1.377	1	4
Previously Abated	14	<LOD[a]	32	1	1.448	1	3
Modern Urban	15	<LOD[a]	40	4	1.316	2	8

[a] Generally <0.6 μg/L

Table 19: Correlations Between Dust Lead Concentrations At The 12-Month Campaign

Pearson Correlation Coefficients / Number of Observations

		Air Duct	Interior Entryway	Floors in Rooms with Windows	Window Sill	Upholstery	Window Well	Floors in Rooms without Windows
Air Duct	r	-	0.41**	0.62**	0.47**	-	0.34**	0.48**
	n		57	57	57	0	56	30
Interior Entryway	r	-	-	0.53**	0.42**	0.32*	0.49**	0.52**
	n			104	104	46	103	55
Floors in Rooms with Windows	r	-	-	-	0.43**	0.23	0.44**	0.53**
	n				104	46	103	55
Window Sill	r	-	-	-	-	0.28	0.61**	0.39**
	n					46	103	55
Upholstery	r	-	-	-	-	-	0.33*	0.42*
	n						46	25
Window Well	r	-	-	-	-	-	-	0.36**
	n							54
Floors in Rooms without Windows	r	-	-	-	-	-	-	-
	n							

* p-value is < .05 ** p-value is < .01

Table 20: Correlations Between Dust Lead Loadings At The 12-Month Campaign

Pearson Correlation Coefficients / Number of Observations

		Air Duct	Interior Entryway	Floors in Rooms with Windows	Window Sill	Upholstery	Window Well	Floors in Rooms without Windows
Air Duct	r	-	0.24	0.27*	0.34**	-	0.30*	-0.01
	n		57	57	57	0	56	30
Interior Entryway	r	-	-	0.37**	0.37**	0.10	0.37**	0.36**
	n			104	104	46	103	55
Floors in Rooms with Windows	r	-	-	-	0.43**	0.23	0.33**	0.39**
	n				104	46	103	55
Window Sill	r	-	-	-	-	0.03	0.67**	0.24
	n					46	103	55
Upholstery	r	-	-	-	-	-	0.03	0.15
	n						46	25
Window Well	r	-	-	-	-	-	-	0.18
	n							54
Floors in Rooms without Windows	r	-	-	-	-	-	-	-
	n							

* p-value is < .05 ** p-value is < .01

Table 21: Correlations Between Dust Loadings At The 12-Month Campaign

Pearson Correlation Coefficients / Number of Observations

		Air Duct	Interior Entryway	Floors in Rooms with Windows	Window Sill	Upholstery	Window Well	Floors in Rooms without Windows
Air Duct	r	-	-0.02	-0.09	0.03	-	-0.10	0.34
	n		57	57	57	0	56	30
Interior Entryway	r	-	-	0.07	0.50**	-0.11	0.26**	-0.01
	n			104	104	46	103	55
Floors in Rooms with Windows	r	-	-	-	0.06	0.06	0.08	0.28*
	n				104	46	103	55
Window Sill	r	-	-	-	-	-0.10	0.70**	-0.04
	n					46	103	55
Upholstery	r	-	-	-	-	-	-0.15	-0.14
	n						46	25
Window Well	r	-	-	-	-	-	-	0.05
	n							54
Floors in Rooms without Windows	r	-	-	-	-	-	-	-
	n							

* p-value is < .05 ** p-value is < .01

Table 22: Correlations Between Blood Lead and Dust Measures Using The Youngest Child Per Household In Continuing Houses At The 12-Month Campaign

Pearson Correlation Coefficients / Number of Observations

Dust Measure Correlated with Blood Lead		SAMPLE TYPE: Interior Entryway	Floors in Rooms with Windows	Floors in Rooms without Windows	Upholstery	Window Sill	Window Well	Air Duct
log of dust lead concentration (µg/g)	r	0.28**	0.44**	0.32*	0.40*	0.18	0.19	0.38**
	n	92	92	50	40	92	91	52
log of dust lead loading (µg/ft²)	r	0.14	0.35**	0.31*	0.42**	0.16	0.09	0.35*
	n	92	92	50	40	92	91	52
log of dust loading (mg/ft²)	r	-0.01	-0.01	0.02	0.22	<0.01	- 0.10	0.13
	n	92	92	50	40	92	91	52

* = p-value is ≤05

** = p-value is ≤01

Table 23: **Correlations Between Blood Lead and Dust Measures Using All Children Per Household In Continuing Houses At The 12-Month Campaign**

Pearson Correlation Coefficients / Number of Observations

Dust Measure Correlated with Blood Lead		SAMPLE TYPE						
		Interior Entryway	Floors in Rooms with Windows	Floors in Rooms without Windows	Upholstery	Window Sill	Window Well	Air Duct
log of dust lead concentration ($\mu g/ft^2$)	r	0.29**	0.44**	0.29*	0.28*	0.20*	0.17	0.47**
	n	125	125	66	59	125	123	66
log of dust lead loading ($\mu g/ft^2$)	r	0.14	0.35**	0.33**	0.33*	0.16	0.08	0.42**
	n	125	125	66	59	125	123	66
log of dust loading (mg/ft^2)	r	<-0.01	<-0.01	0.05	0.17	<-0.01	-0.10	0.15
	n	125	125	66	59	125	123	66

* = p-value is ≤.05
** = p-value is ≤.01

7.3 Longitudinal Data Analysis

Environmental Dust Model

The environmental dust model (described in section 6.3) was developed for the data for lead loadings, lead concentrations, and dust loadings. The dependent variable for the environmental model, called factor1, was obtained from a factor analysis and accounted for most of the variability of environmental dust lead.

Figures 23(a-c) are plots of the least square mean estimates for each of the three dust endpoints (lead loadings and concentrations, and dust loadings) derived from the environmental model when fit to data from the three R&M groups only. Figures 24(a-c) are plots of the least square mean estimates derived from the same model fit to data from all five groups. Note that solid lines are used to connect the points in these plots. This is done for ease of display. These lines should not be taken to indicate that trends in the intervals between campaigns are known. Study group, campaign and the interaction of study group and campaign were found to be statistically significant in all six applications of the environmental model, after controlling for season. Season was found to have a significant fixed effect only in the models fit to the dust loading data. The significant interaction term indicates that the relationship between group and campaign for the three dust endpoints is not the same across study groups. The main findings of the applications of the environmental model are listed below.

Environmental Dust Model -- Comparison Of Groups At Specific Campaigns

- Pre-intervention dust lead loadings were significantly higher in R&M III houses than in R&M I and R&M II houses. Statistically significant differences were found between the three R&M groups at each post-intervention campaign, except for between R&M I houses and R&M II houses at two months. During follow-up, R&M III houses consistently had the lowest lead loadings, R&M I the highest lead loadings, and R&M II had intermediate lead loadings. Modern urban houses had statistically significantly lower lead loadings than each of the other four study groups at each campaign.

- Pre-intervention dust lead concentrations were not significantly different across the three R&M groups. Lead concentrations were significantly lower (generally $p < .01$) in R&M III houses than in R&M I and R&M II houses at immediate post-intervention, two months, six months, and at 12 months. During follow-up, dust lead concentration was lowest in R&M III houses, highest in R&M I houses, and intermediate in R&M II houses. Only at 12 months, were lead concentrations in R&M II houses significantly lower than those in R&M I houses. R&M I-III houses and previously abated house all had significantly higher dust lead concentrations during follow-up than modern urban houses. Lead concentrations in R&M III houses were not significantly different from those in previously abated houses at six months and 12 months.

- At pre-intervention, dust loadings were significantly higher in R&M III houses than in R&M I and R&M II houses. Except for at two months post-intervention, dust loadings in R&M III houses were significantly less than those in R&M I houses. R&M II houses had intermediate dust loadings at each follow-up campaign; they were statistically significantly less than those in R&M I houses at post-intervention and at 12 months. Dust loadings in the modern urban houses were not statistically significantly different from those in the other four groups at six months and 12 months.

Environmental Dust Model -- Changes Over Time Within Groups

- For all three R&M groups, lead loadings during follow-up were statistically significantly lower than the corresponding pre-intervention lead loadings. Lead loadings at two months, six months, and 12 months were significantly higher than the corresponding immediately post-intervention lead loadings, except for R&M I houses at two months. Further, no statistically significant changes in dust lead loadings were found within any of the R&M groups between two months and 12 months post-intervention.

- R&M I intervention was not associated with a statistically significant reduction in dust lead concentration. In R&M II and R&M III houses, lead concentrations were significantly lower at all post-intervention campaigns compared to baseline, except for R&M II houses at immediately post-intervention. R&M III was the only R&M group to have a significant reduction in lead concentration immediately after the intervention.

- Dust loadings were reduced significantly immediately post-intervention and remained significantly below pre-intervention levels during the first year in all there groups of R&M houses, despite significant increases in dust loadings at two months in R&M II and R&M III houses.

- Statistically significant changes were not found for dust lead loadings, lead concentrations and dust loadings in modern urban and previously abated houses during the first year of follow-up, despite downward trends in lead loadings and dust loadings in both groups.

Blood Lead Comparison Model

The main findings of the comparison model (see section 6.3) for investigating blood lead changes within and between groups are listed below. The model was fit separately for children with initial blood lead concentrations <20 μg/dL and for those with blood lead concentrations ≥ 20 μg/dL. Figures 25(a,b) and 26(a,b) are plots of the predicted blood lead concentrations based on the longitudinal data analysis of children with baseline blood lead concentrations <20 μg/dL in the three R&M groups and in all five study groups. Table 24 displays the predicted blood lead concentrations with 95 percent confidence intervals for children with initial blood lead concentrations <20 μg/dL, by study group.

Children With Baseline Blood Lead Concentration <20 µg/dL

- The interaction between group and campaign was not statistically significant and the models were refitted without the interaction term. Age and season, but not gender, were found to be statistically significant in all applications of the comparison model.

- For children with baseline blood lead concentrations <20 µg/dL, no statistically significant differences in blood lead concentration were found between and within R&M groups during the first year of follow-up, controlling for age, gender and season. Group and campaign were not found to be significant in this analysis. R&M I children tended to have lower blood lead concentrations at each campaign, including baseline, compared to R&M III children. The group variable was statistically significant in the five group model when controlling for age, gender, and season.

- Controlling for age and season, children in modern urban houses had blood lead concentrations that were statistically lower than those of children in each of the other four study groups at the initial, six-month, and 12-month campaigns. Children in the modern urban houses had a small, but statistically nonsignificant, increase in blood lead concentration over baseline at the six-month campaign.

- Children with initial blood lead concentrations <20 µg/dL in the previously abated control houses had no statistically significant blood lead changes at the six-month and 12-month campaigns, controlling for age, gender, and season.

Children With Baseline Blood Lead Concentrations ≥ 20 µg/dL

- None of the children in the modern urban group had blood lead concentrations ≥ 11 µg/dL. For the 19 children in the other four groups with initial blood lead concentration ≥ 20 µg/dL, a statistically significant downward trend in blood lead concentration was found during the first year of follow-up, when controlling for age, season, and group. (Only one child in the R&M I group had an initial blood lead concentration ≥ 20 µg/dL).

Table 24: **Predicted Blood Lead Concentration (PbB, μg/dL) By Group And By Campaign In Children With Initial PbB<20 μg/dL***

Study Group	Initial Campaign Predicted PbB (95% CI)	Two Month Campaign Predicted PbB (95% CI)	Six Month Campaign Predicted PbB (95% CI)	Twelve Month Campaign Predicted PbB (95% CI)
R&M I	8.8 (7.6 to 10.3)	8.8 (7.3 to 10.4)	9.0 (7.6 to 10.7)	7.8 (6.1 to 9.8)
R&M II	10.5 (9.2 to 11.9)	11.2 (9.7 to 12.9)	11.6 (10.2 to 13.2)	10.3 (9.0 to 11.9)
R&M III	11.3 (9.9 to 13.0)	12.4 (10.4 to 14.8)	11.9 (10.1 to 14.0)	10.7 (9.2 to 12.5)
Previously Abated	11.7 (10.7 to 12.8)	not applicable	13.7 (12.2 to 15.5)	12.2 (10.9 to 13.5)
Modern Urban	3.3 (2.9 to 3.8)	not applicable	3.8 (3.2 to 4.5)	3.6 (3.1 to 4.1)

* Based on the application of the comparison model for longitudinal data analysis described in section 6.3)

Exposure Model Fitted To Blood Lead Concentration Data

The main findings of the exposure models (see section 6.3) used to investigate the relationship between blood lead concentration and dust lead (loading and concentration) are below:

- Age, age^3, and season (summer vs nonsummer) were significant contributors to the model for the three R&M groups and for all five groups. Gender and hand-to-mouth activity (high vs low) were not found to be consistently significant contributors to the model.[e]

- Controlling for age, campaign, dust factor1, and factor2, the seasonal change in children's blood lead concentration was estimated to be +1.2 μg/dL in summer, relative to the other seasons.

- Using all five study groups in the model, dust lead loadings and concentrations (factor1 and factor2) were significantly related to children's blood lead concentration after adjusting for age, season, campaign and the inclusion of random effects for houses and multiple children in each house. Factor1 and factor2 were not found to be significant contributors to the model for the three R&M groups.

- The interactions of factor1 and factor2 with campaign were not statistically significant for lead concentration factors and lead loading factors. For this reason, the exposure models do not include these interaction terms.

Figures 27a and 27b are partial-residual plots of blood lead concentration versus factor1 dust lead loading and factor1 dust lead concentration, derived from the exposure model for all five study groups. These types of plots reflect the relationship between the dependent variable (blood lead concentration) and a specific independent variable (factor1 dust lead) after both variables are adjusted for all of the other independent variables in the model. The slope of the regression line in the figure is non-zero and positive, indicating a statistically significant relationship between blood lead concentration and dust lead loading, and between blood lead concentration and dust lead concentration. The positive slope indicates that blood lead concentration increases as exposure increases. Factor1 is a composite measure of lead exposure in a house based on a linear combination of floor, window sill, and window well lead loadings or lead concentration data. Due to the nature of factor1, it is not possible to interpret the model findings in terms of a unit change in blood lead concentration predicted for a unit change in factor1. These partial-residual plots also indicate that the model assumptions, with respect to the normal distribution of residuals, is not violated.

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[e] One measure of hand-to-mouth activity had borderline statistical significance using data from all five study groups through the 12-month campaign. Within some groups, one of the various measures of hand-to-mouth activity reached statistical significance (.05), or borderline significance.

Carpet Dust Data

Although this study was not designed to study carpets, longitudinal data analysis was performed to determine whether dust lead loadings and concentrations and dust loadings varied by the amount of carpet included in the composite dust samples from floors. Dust loadings and dust lead loadings tended to increase as the amount of carpet area included in composite samples increased, when accounting for group, campaign, the interaction of group and campaign, and story (1st vs 2nd floor). Dust lead concentrations, however, decreased slightly. This pattern of findings suggests that carpets are dust traps or sinks. The significance of this pattern is not clear; other analyses indicated that the amount of carpet included in composite samples was not a predictor of children's blood lead concentrations.

Figure 23a: Lead Concentation Least Square Mean Estimates

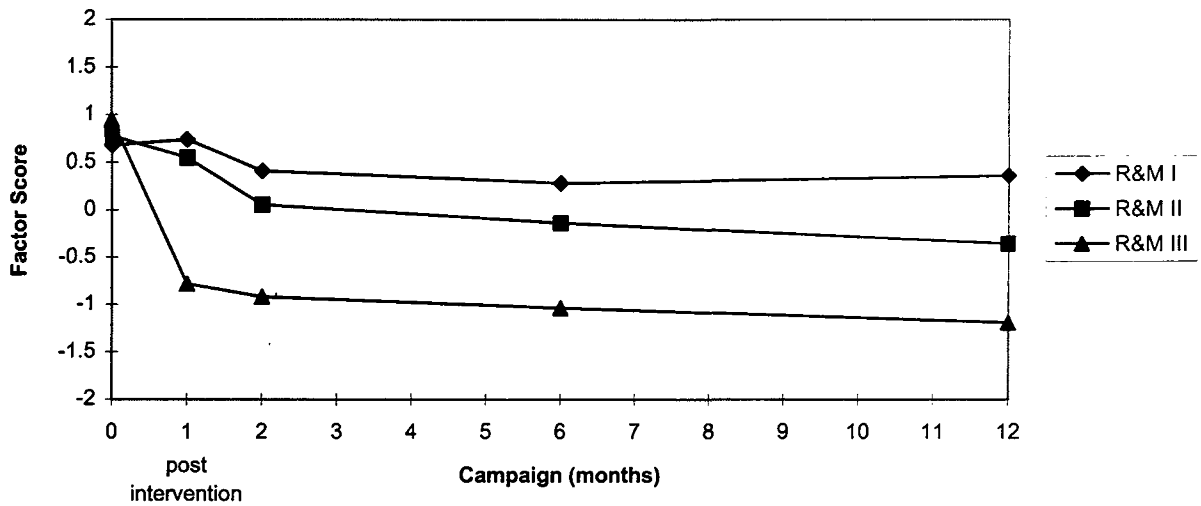


Figure 23b: Dust Loading Least Square Estimates

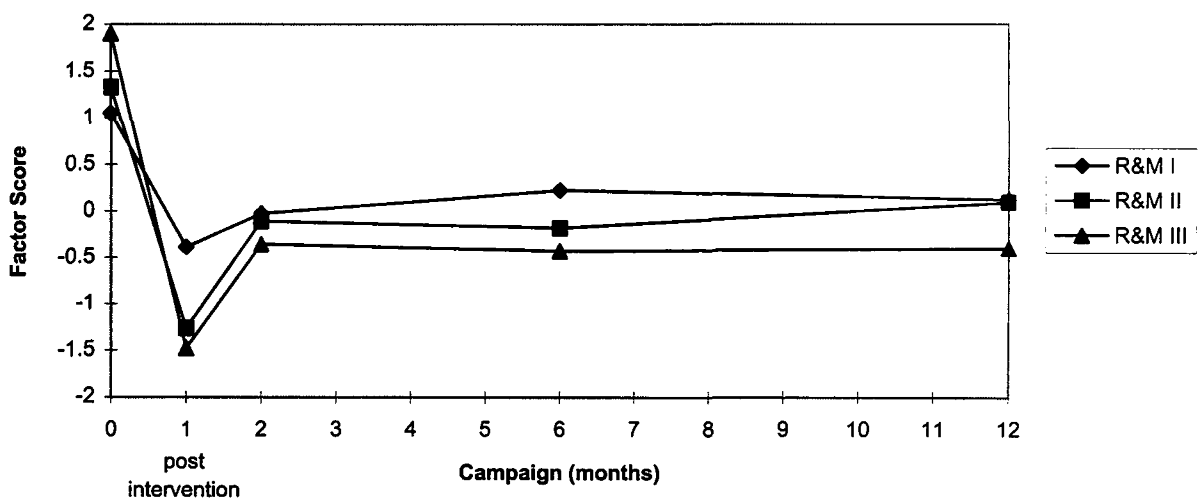


Figure 23c: Lead Loading Least Square Estimates

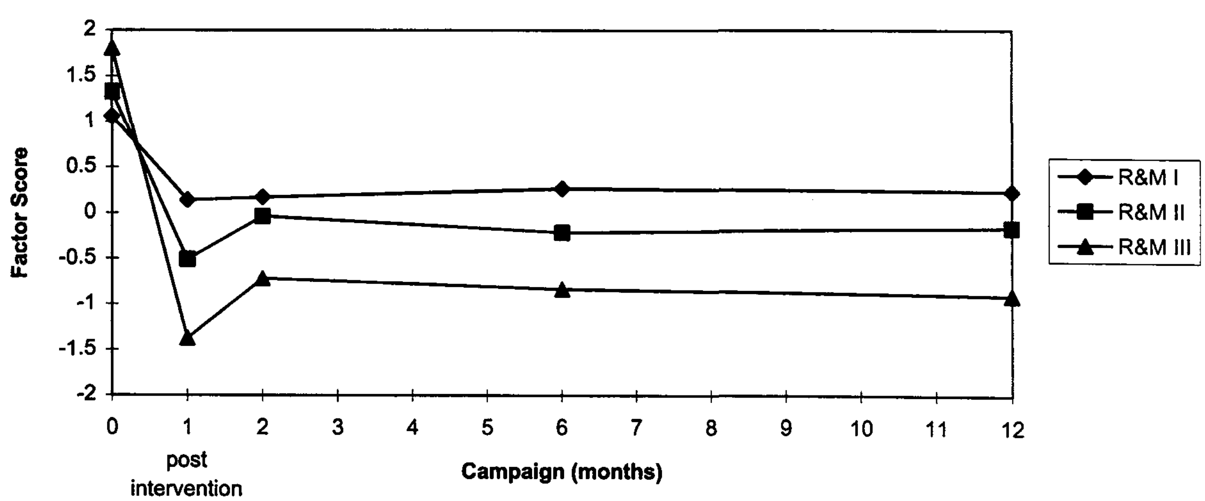


Figure 24a: Lead Concentration Least Square Means

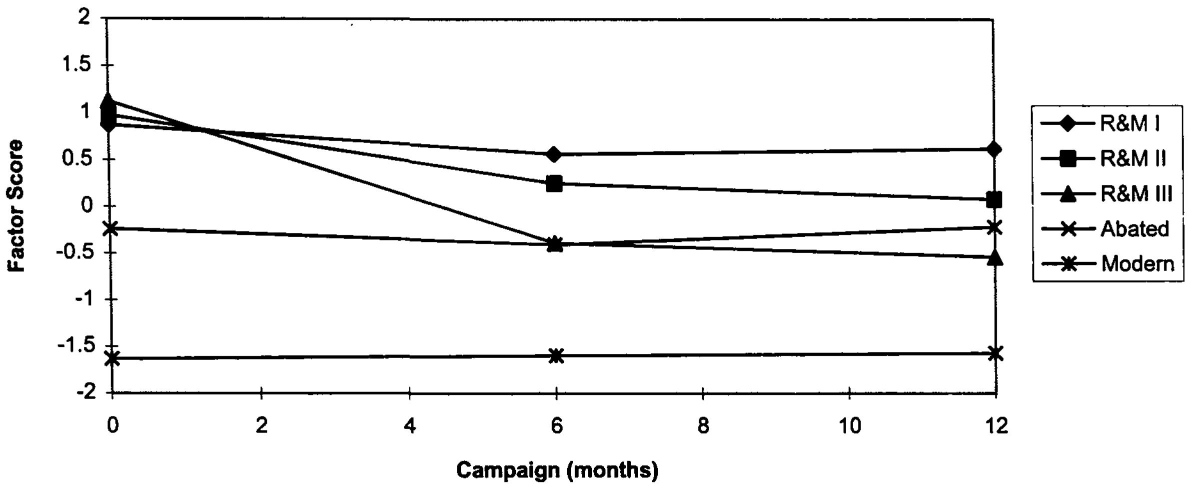


Figure 24b: Dust Loading Least Square Mean Estimates

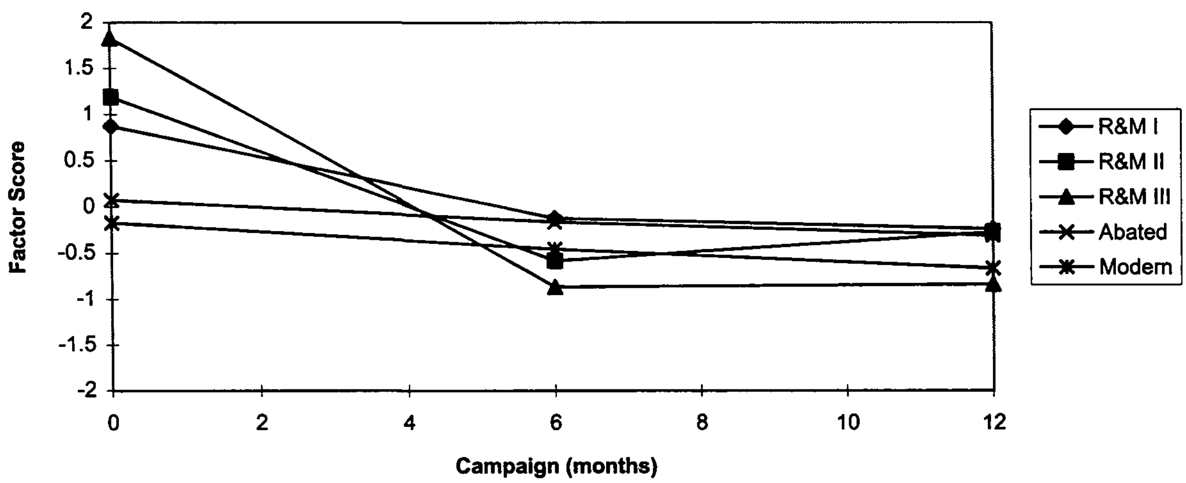


Figure 24c: Lead Loading Least Square Mean Estimates

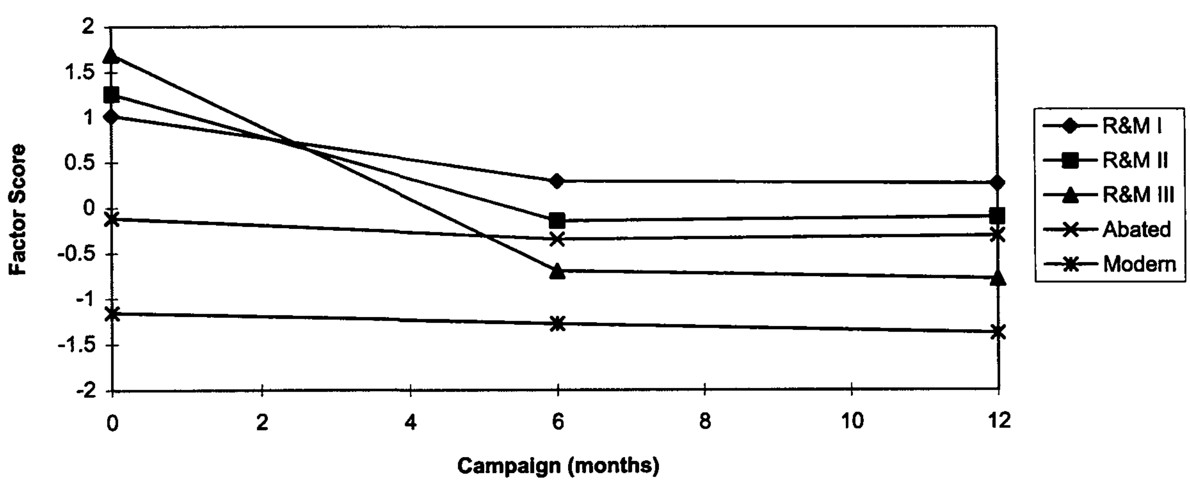


Figure 25a: Comparison Model With Initial PbB < 20

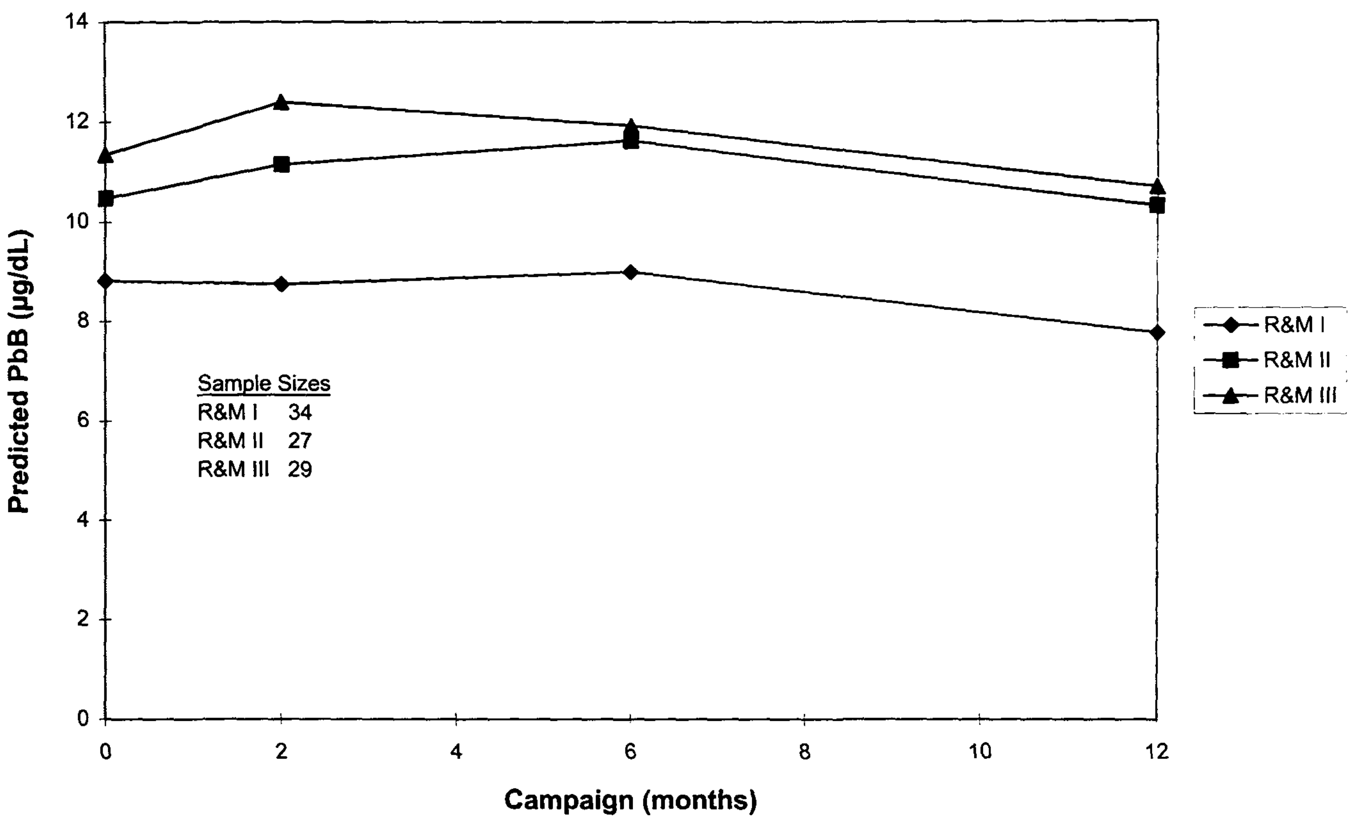


Figure 25b: Comparison Model With Initial PbB < 20

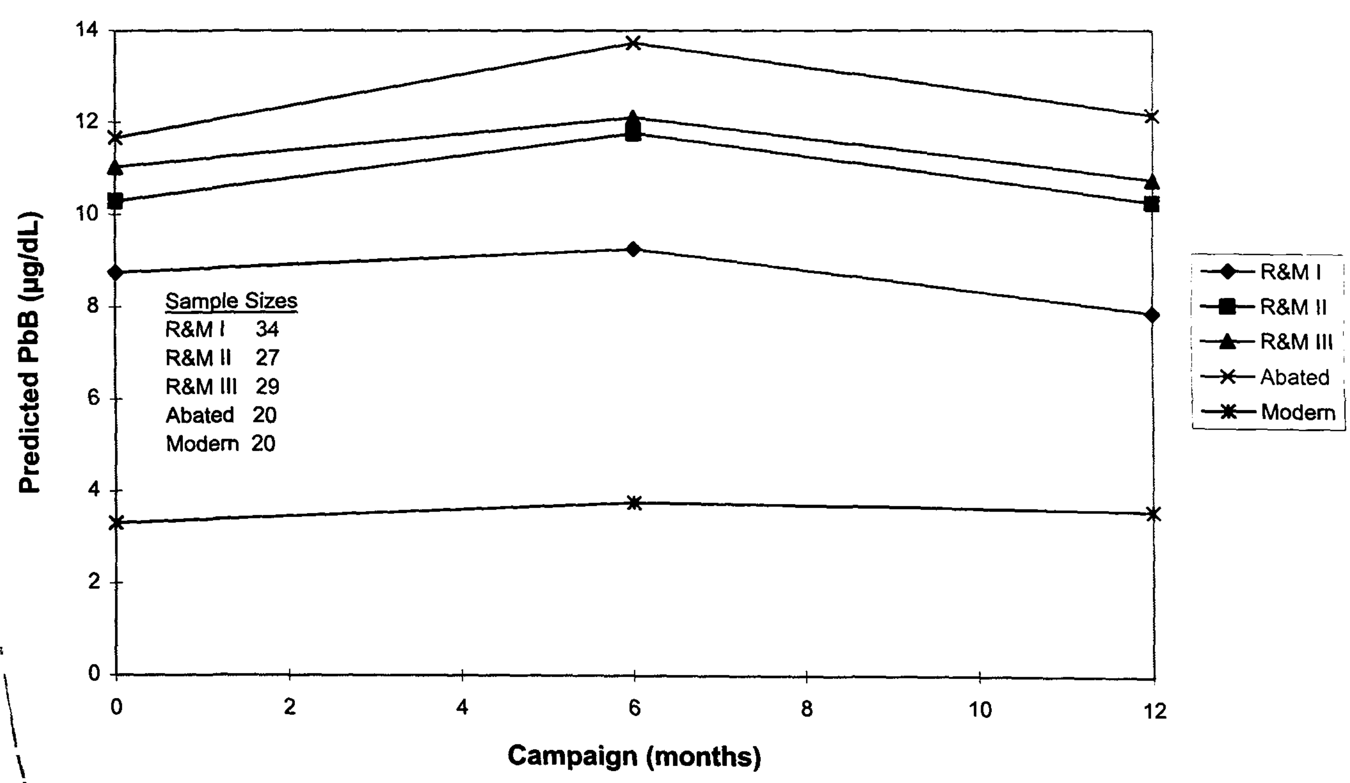


Figure 26a: Comparison Model With Initial PbB ≥ 20

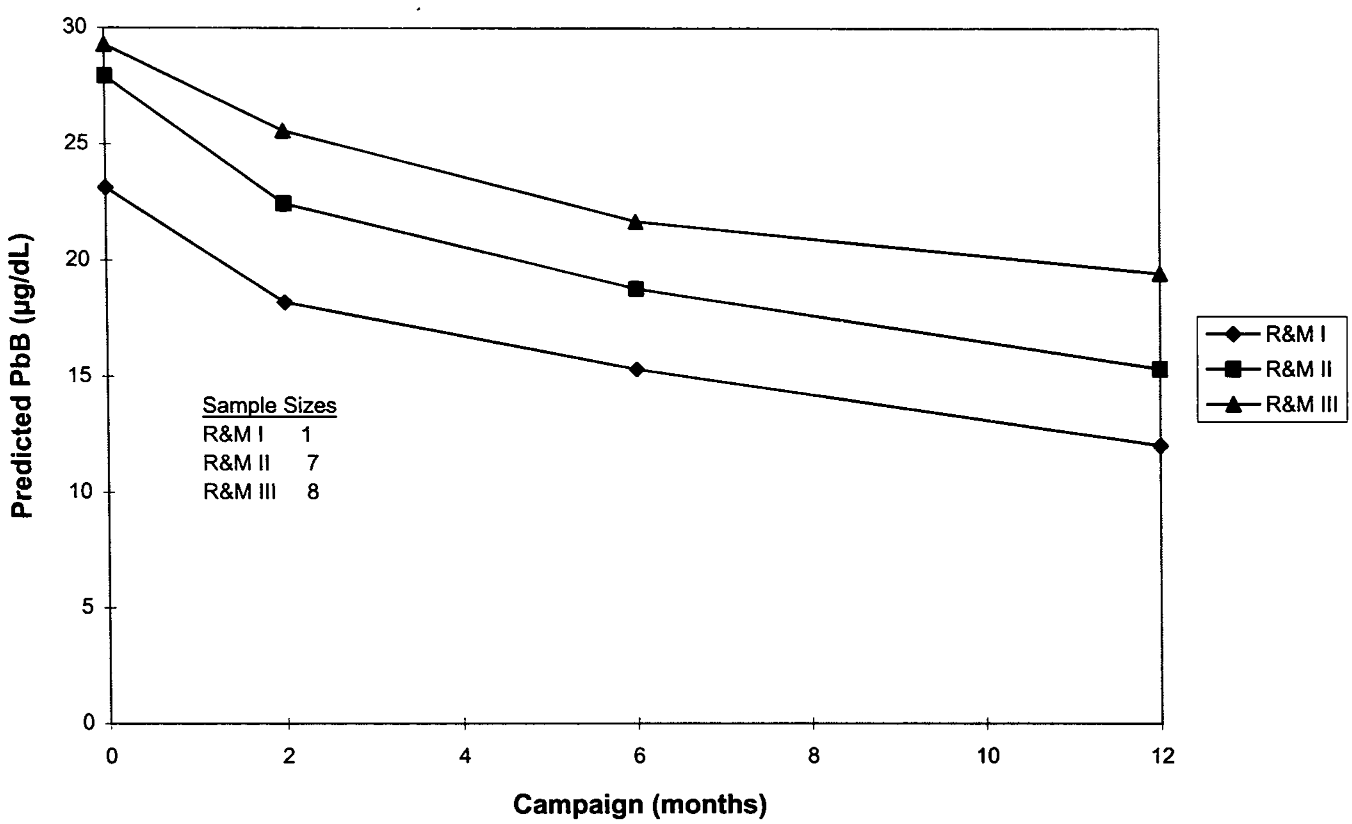


Figure 26b: Comparison Model With Initial PbB ≥ 20

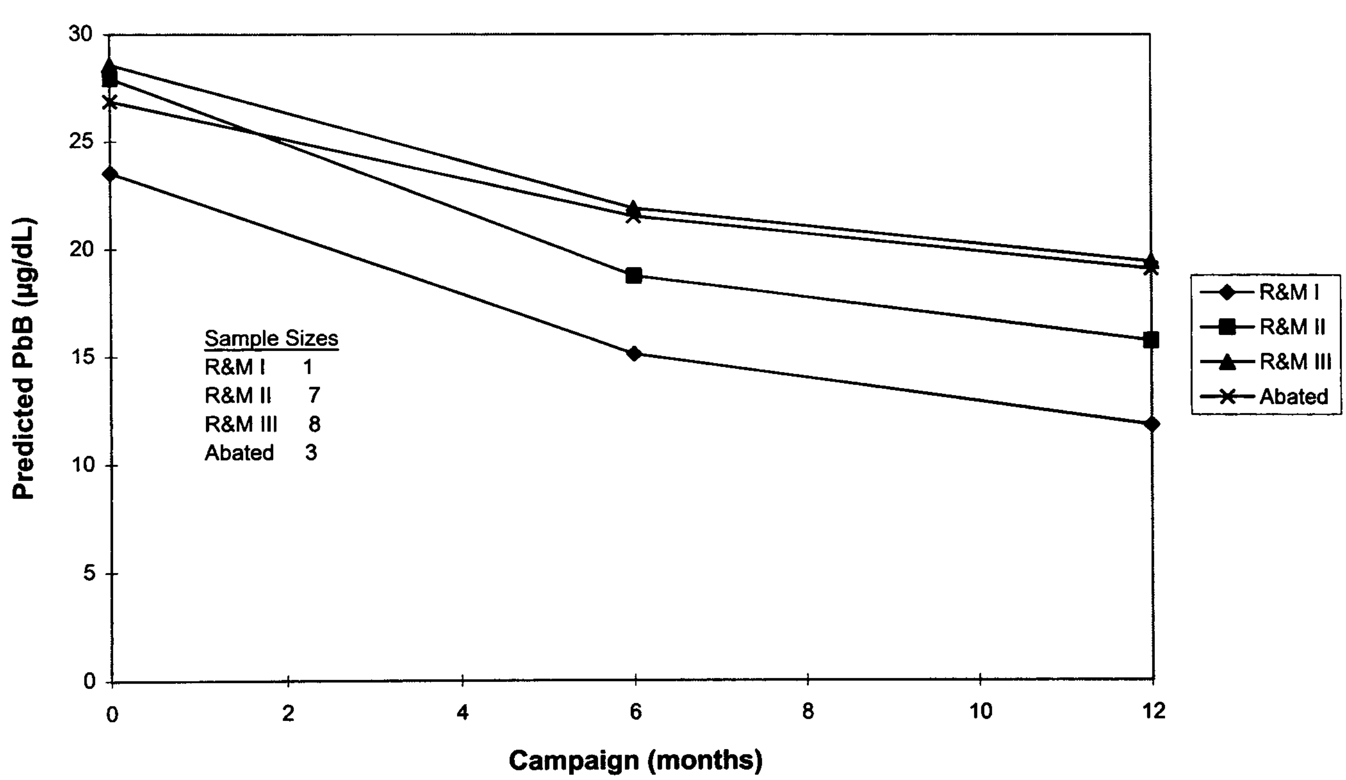


Figure 27a: All Groups Lead Loading Exposure Model Adjusted Residual Plot

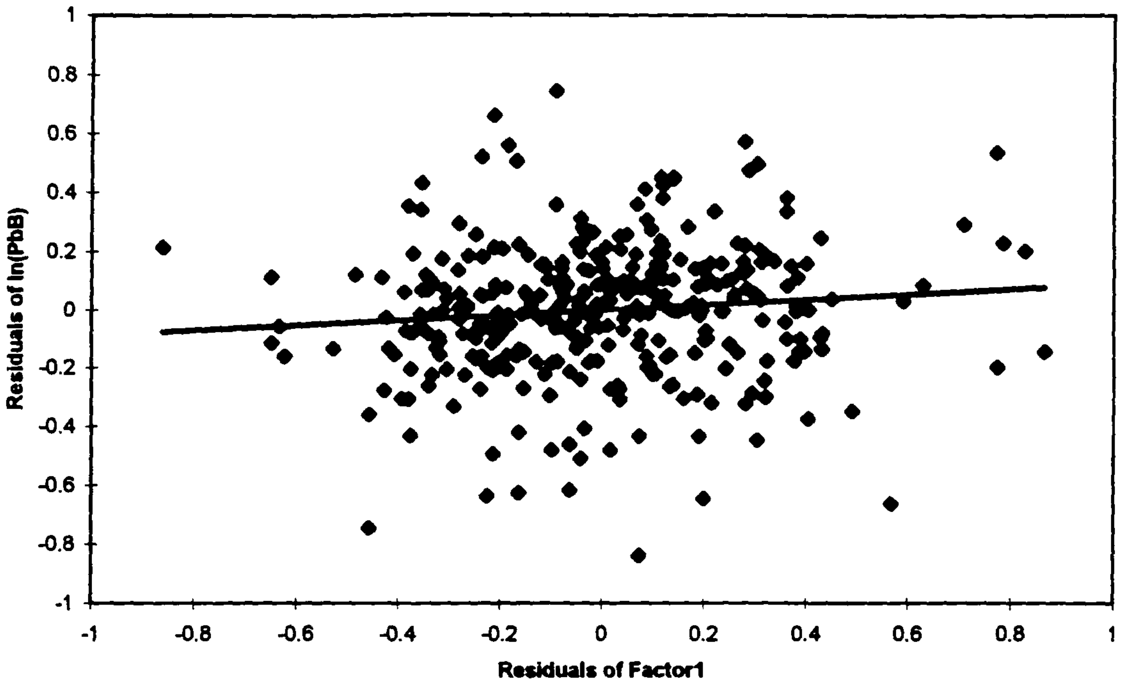
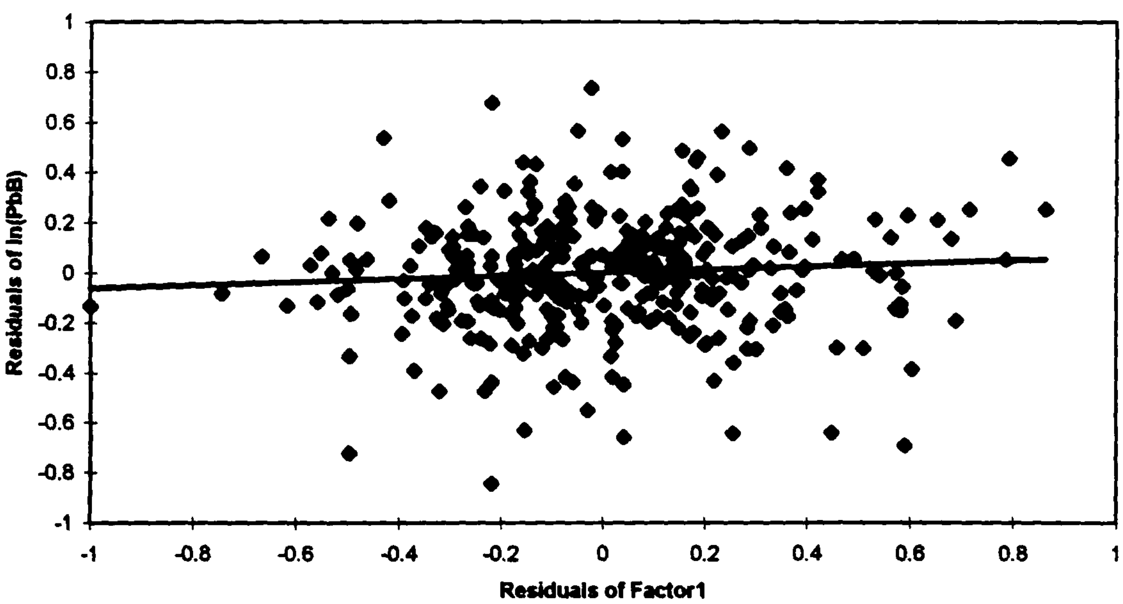


Figure 27b: All Groups Lead Concentration Exposure Model Adjusted Residual Plot



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APPENDIX A

Descriptive Statistics on Dust Data

Table A-1: Descriptive Statistics For Dust Lead Concentrations By Surface Type And Study Group At The 12-Month Campaign

Surface Type	Study Group	n	Minimum (µg/g)	Maximum (µg/g)	Geometric Mean[a] (µg/g)	S.D. on log scale	Lower 95% CI for GM (µg/g)	Upper 95% CI for GM (µg/g)
Air Duct	R&M-I	10	91	24,150	1,152	1.506	392	3,384
	R&M-II	15	107	11,348	802	1.396	370	1,738
	R&M-III	16	168	5,226	958	0.953	577	1,592
	Previously Abated	5	167	5,841	1,138	1.632	150	8,628
	Modern Urban	11	18	4,464	101	1.585	35	293
Interior Entryway	R&M-I	25	262	704,065	1,498	1.546	791	2,836
	R&M-II	23	155	12,478	1,094	1.028	701	1,706
	R&M-III	27	37	4,887	692	0.968	472	1,015
	Previously Abated	14	196	7,741	1,106	1.108	583	2,096
	Modern Urban	15	21	777	119	0.961	70	203
Floors in Rooms with Windows	R&M-I	53	140	11,977	811	1.004	604	1,089
	R&M-II	46	85	8,714	674	1.009	461	987
	R&M-III	54	67	25,605	608	1.209	405	914
	Previously Abated	28	11	8,894	570	1.332	317	1,022
	Modern Urban	31	13	1,085	79	0.796	58	108
Floors in Rooms without Windows	R&M-I	17	175	9,674	642	1.095	365	1,127
	R&M-II	15	72	58,840	905	1.784	337	2,431
	R&M-III	13	169	1,419	525	0.720	340	811
	Previously Abated	6	56	6,190	966	1.636	174	5,377
	Modern Urban	4	2	152	15	1.758	1	252
Window Sill	R&M-I	49	626	93,917	6,964	1.172	4.815	10,071
	R&M-II	46	94	39,009	3,165	1.463	1.865	5,371
	R&M-III	54	172	52,598	881	1.218	602	1,289
	Previously Abated	28	193	132,312	1,138	1.388	606	2,139
	Modern Urban	30	31	1,742	267	0.968	171	417
Upholstery	R&M-I	15	91	2,195	499	0.797	321	775
	R&M-II	7	258	2,364	477	0.741	240	947
	R&M-III	11	149	973	385	0.663	247	602
	Previously Abated	9	215	770	394	0.485	271	571
	Modern Urban	4	89	461	206	0.679	70	606
Window Well	R&M-I	45	1,569	493,006	20,921	1.156	14,646	29,886
	R&M-II	46	101	151,924	4,989	1.481	2,986	8,335
	R&M-III	54	3	29,576	1,071	1.251	733	1,564
	Previously Abated	28	274	45,214	3,031	1.650	1,333	6,893
	Modern Urban	30	91	8,734	438	0.909	296	648

[a] GM values and confidence intervals for floors (rooms with windows), window sills, and window wells were obtained from SAS® PROC MIXED

Table A-2: Descriptive Statistics For Dust Lead Loadings By Surface Type And Study Group At The 12-Month Campaign

Surface Type	Study Group	n	Minimum ($\mu g/ft^2$)	Maximum ($\mu g/ft^2$)	Geometric Mean[a] ($\mu g/ft^2$)	S.D. on log scale	Lower 95% CI for GM ($\mu g/ft^2$)	Upper 95% CI for GM ($\mu g/ft^2$)
Air Duct	R&M-I	10	245	3,755,278	13,239	3.054	1,489	117,685
	R&M-II	15	31	596,898	15,237	2.563	3,686	62,985
	R&M-III	16	144	874,350	12,040	2.032	4,077	35,554
	Previously Abated	5	326	180,703	10,020	2.394	513	195,779
	Modern Urban	11	112	14,428	856	1.760	262	2,794
Interior Entryway	R&M-I	25	21	45,201	365	1.927	165	808
	R&M-II	23	7	9,574	215	2.001	91	511
	R&M-III	27	1	1,452	94	1.792	46	191
	Previously Abated	14	8	15,204	119	2.260	32	440
	Modern Urban	15	1	391	30	1.383	14	64
Floor in Rooms with Windows	R&M-I	53	6	25,581	94	1.443	61	144
	R&M-II	46	4	4,416	76	1.454	43	134
	R&M-III	54	2	3,441	50	1.613	29	87
	Previously Abated	28	<1	2,424	77	2.006	32	187
	Modern Urban	31	<1	107	8	1.138	5	13
Floors in Rooms without Windows	R&M-I	17	8	513	56	1.377	28	114
	R&M-II	15	1	7,580	53	2.208	16	179
	R&M-III	13	7	444	44	1.345	19	99
	Previously Abated	6	5	856	108	1.724	18	662
	Modern Urban	4	<1	3	1	0.901	<1	4
Window Sill	R&M-I	49	5	7,523	470	1.895	254	871
	R&M-II	46	1	10,053	237	2.224	102	550
	R&M-III	54	1	683	29	1.621	17	50
	Previously Abated	28	4	24,481	75	1.756	34	168
	Modern Urban	30	2	40	9	0.815	6	13
Upholstery	R&M-I	15	1	158	36	1.302	17	74
	R&M-II	7	33	824	104	1.175	35	308
	R&M-III	11	7	744	64	1.591	22	187
	Previously Abated	9	6	82	20	0.982	10	43
	Modern Urban	4	1	24	7	1.318	1	61
Window Well	R&M-I	45	548	367,432	16,698	1.450	10,146	27,479
	R&M-II	46	6	163,334	2,587	2.271	1,084	6,173
	R&M-III	54	2	29,430	220	1.580	137	353
	Previously Abated	28	52	22,872	1,164	1.904	492	2,751
	Modern Urban	30	9	2,410	208	1.447	104	416

a GM values and confidence intervals for floors (rooms with windows), window sills, and window wells were obtained from SAS® PROC MIXED

Table A-3: Descriptive Statistics For Dust Loadings By Surface Type And Study Group At The 12-Month Campaign

Surface Type	Study Group	n	Minimum (mg/ft²)	Maximum (mg/ft²)	Geometric Mean[a] (mg/ft²)	S.D. on log scale	Lower 95% CI for GM (mg/ft²)	Upper 95% CI for GM (mg/ft²)
Air Duct	R&M-I	10	354	155,499	11,492	2.138	2,489	53,051
	R&M-II	15	283	103,878	18,999	1.834	6,882	52,454
	R&M-III	16	94	167,309	12,566	1.904	4,556	34,657
	Previously Abated	5	1,951	34,803	8,807	1.090	2,274	34,107
	Modern Urban	11	1,222	176,990	8,474	1.560	2,972	24,161
Interior Entryway	R&M-I	25	10	8,077	244	1.594	126	471
	R&M-II	23	19	2,330	197	1.348	110	352
	R&M-III	27	13	1,941	136	1.297	81	227
	Previously Abated	14	2	2,669	108	1.835	37	311
	Modern Urban	15	11	760	250	1.026	141	441
Floors in Rooms with Windows	R&M-I	53	14	8,924	115	1.112	80	166
	R&M-II	46	15	981	113	1.069	76	167
	R&M-III	54	17	617	82	0.937	63	108
	Previously Abated	28	18	749	135	1.141	82	221
	Modern Urban	31	6	675	100	1.072	62	162
Floors in Rooms without Windows	R&M-I	17	17	459	87	1.164	48	159
	R&M-II	15	3	509	58	1.260	29	117
	R&M-III	13	13	562	84	1.077	44	160
	Previously Abated	6	49	156	112	0.451	70	180
	Modern Urban	4	21	292	62	1.110	11	361
Window Sill	R&M-I	49	5	1,901	67	1.222	45	101
	R&M-II	46	5	1,742	75	1.243	50	111
	R&M-III	54	<1	264	33	1.221	22	49
	Previously Abated	28	8	576	66	1.160	41	107
	Modern Urban	30	8	354	32	0.953	21	50
Upholstery	R&M-I	15	11	407	72	1.115	39	133
	R&M-II	7	70	1,854	218	1.029	84	565
	R&M-III	11	17	2,704	167	1.407	65	429
	Previously Abated	9	12	214	52	0.937	25	107
	Modern Urban	4	14	87	36	0.791	10	128
Window Well	R&M-I	45	68	10,988	777	0.975	566	1,067
	R&M-II	46	12	10,548	519	1.432	306	879
	R&M-III	54	9	1,592	205	1.252	135	312
	Previously Abated	28	33	5,496	384	1.053	250	590
	Modern Urban	30	28	3,307	476	1.223	255	888

[a] GM values and confidence intervals for floors (rooms with windows), window sills, and window wells were obtained from SAS® PROC MIXED

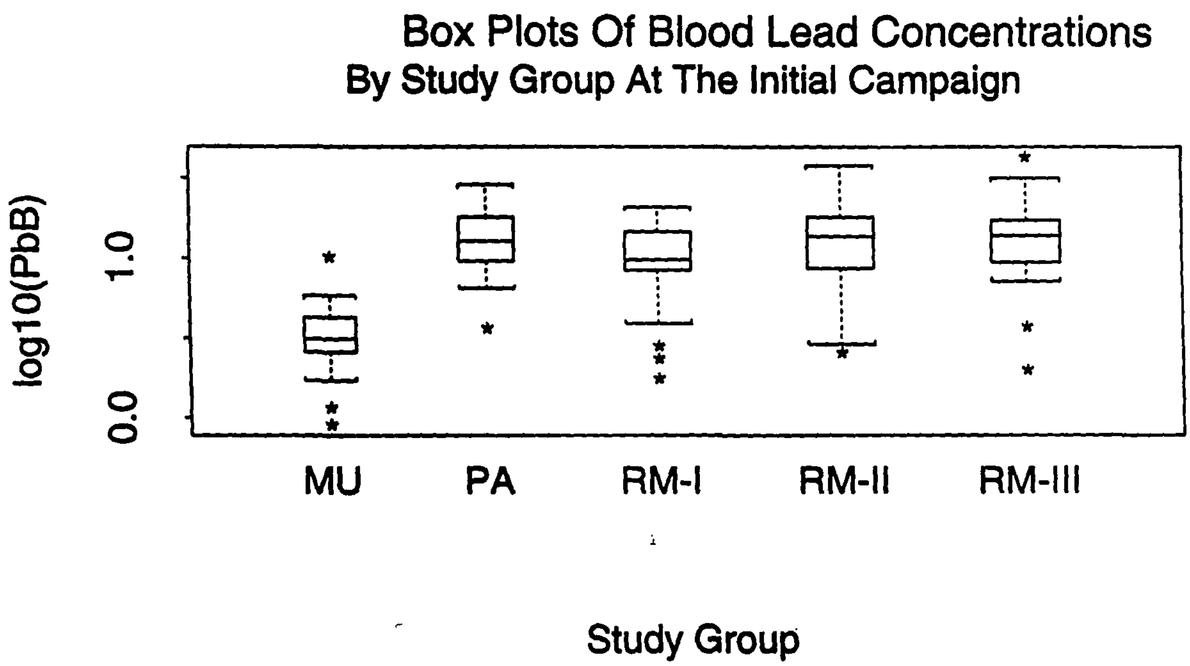
APPENDIX B:

Descriptive Statistics for Baseline Blood Lead Concentrations by Group

Table B-1: Descriptive Statistics For Blood Lead Concentrations By Group At Initial Campaign

Study Group	Minimum (μg/dL)	Maximum (μg/dL)	Geometric Mean[a] (μg/dL)	S.D. on log scale	Lower 95% CI for GM (μg/dL)	Upper 95% CI for GM (μg/dL)
R&M Level I	2.0	22.0	9.9	0.539	7.9	12.3
R&M Level II	3.5	36.0	13.8	0.531	11.2	16.9
R&M Level III	2.0	42.0	14.2	0.542	11.3	17.9
Previously Abated	3.5	28.0	12.8	0.495	10.2	16.1
Modern Urban	2.0	10.0	4.8	0.457	3.8	6.1

[a] GM values and confidence intervals were obtained from SAS® PROC MIXED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9. Performing Organization Name and Address Kennedy Krieger Research Institute (KKRI) 707 N. Broadway Baltimore, MD 21205	10. Project/Task/Work Unit No.
	11. Contract © or Grant (G) No. Contract # 68-D4-0001
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency Office of Pollution, Pesticide and Toxic Substances Washington, D.C. 20460	13. Type of Report & Period Covered Final Report; 1995-96
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15. Supplementary Notes

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16. Abstract (Limit: 200 words)

This report presents the first year of follow-up of the Lead-Based Abatement and Repair and Maintenance (R&M) Study in Baltimore. The R&M study is designed to characterize and compare the short (2-6 months) and long-term (12-24 months) effectiveness of three levels of interim control interventions in low-income housing where children are at high risk of exposure to lead in dust and paint. The study has two control groups, i.e., urban houses built after 1979 when paint was presumably free of lead, and previously abated houses that received comprehensive abatement in the past. The study population consists of non-Hispanic black households with at least one participating child. At the onset, the mean ages of study children ranged form 25 months to 33 months across groups. The main findings based on dust lead and blood lead data from five study groups collected during the pre- and post-intervention campaigns, as well as during the two, six and 12 months post-intervention data collection campaigns are presented.

17. Document Analysis

a. Descriptors: Kennedy Craggier Research Institutes, lead, lead dust testing, blood lead testing, lead-based paint, lead-dust loading, lead-dust concentration, dust loading, low cost repair and maintenance interventions, children's blood lead, lead exposure reduction in children, lead hazard reduction, blood lead-dust lead correlation.

b. Identifiers/Open-Ended Terms: Lead poisoning, lead abatement, interim control, inductively coupled plasma emission spectroscopy (ICP- AES), flame atomic absorption spectroscopy (FAAS), graphite furnace atomic absorption spectroscopy (GFAAS), cyclone-based dust collector, Baltimore Repair and Maintenance dust collector (BRM).

c. Caseate Field/Group:

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