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FINAL REPORT

SAMPLING HOUSE DUST FOR LEAD

Basic Concepts and Literature Review

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This report was prepared as part of a separate laboratory investigation into the efficiency of household dust sampling methods and common commercial household vacuum cleaners for collecting lead dust found in residential housing. The report describes the wide variety of sampling methods that are available for collecting household dust, reviews current literature on the topic, and makes conclusions and recommendations for additional research. This report was prepared by Westat, Inc., under contract to the Environmental Protection Agency. The responsibilities of each organization are listed below.

Westat, Inc.

Westat was responsible for conducting and summarizing the research, and for writing and editing the report.

U.S. Environmental Protection Agency (EPA)

EPA was responsible for funding the project, for reviewing the report, and for arranging the peer review of the report. The EPA Work Assignment Manager was John Schwemberger. The EPA Project Officers were Sam Brown and John Varhol.

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA), under Section 403 of the Residential Lead-Based Paint Hazard Reduction Act of 1992 (Title X), is developing numerical standards to protect the public from the lead hazards associated with house dust. It is expected that these standards will be used and cited extensively in the United States to characterize the lead poisoning risks to children.

This report provides a background for standardizing house dust sampling techniques so that Section 403 standards, once developed, can be used consistently and effectively. The report explains basic concepts, summarizes the house dust sampling methods described in the literature, and discusses sampling strategies and their implications for meaningful and cost-effective dust collection. The report also gives conclusions and recommendations for future research.

There is currently a substantial amount of research being done to develop and characterize house dust sampling methods. However, scientists do not agree on either the definition of house dust or the methods to measure it. This issue is complicated by the fact that results from one house dust sampling method may not be directly comparable to results from others.

When the results from house dust sampling studies are reviewed, it is important to know which sampling method was used and how it was used. Differences in sampling methods, sampling locations, the size of areas sampled, and the time the sample was taken in relation to cleaning activities may be particularly important when the results are used to predict children's blood lead levels.

There are other study factors that need to be analyzed carefully. For example, it is important to understand that the type of surface from which the dust is sampled affects the efficiency of dust collection from the surface. Furthermore, different sampling methods recover different amounts of total dust from the same sampled surface, due to different collection efficiencies of the samplers. Differences in collection efficiency on different surface types and among sampling devices may influence measurements of lead levels in house dust.

As this report shows, much research has been done and much still remains to be done. One important area for further research is the development of a standardized method to characterize house dust samplers to establish a baseline for the future. Ideally, these characterization studies will be conducted in the field using information on children's blood lead levels. After these analyses are complete, it may be possible to compare different sampling methods and make meaningful interpretations of the inherent differences in results from one method to another. The Section 403 dust lead standards, when they are eventually developed, may need to be adjusted for a particular sampler. The ability to adjust sampling results based on their actual relationship to children's blood lead levels is necessary because many of the different sampling methods described in this report will continue to be used for the foreseeable future.

Further research is also needed to examine the dust/blood lead linkages. Numerous studies have documented this relationship but usually with only one sampling method and one sampling strategy. Additional studies are needed to assess different sampling methods side by side and to assess various strategies (e.g., single surface vs. composite sampling) and then compare these relationships to children's blood lead levels. Because the existing data is limited or questionable, further research is needed on the characteristics of dust that sticks to children's hands and the characteristics of the house dust that is ingested. New, powerful, analytical research tools are available today that may permit a close look at the properties of this dust. Therefore, dust adherence to children's hands can be re-examined to see if new findings with more sophisticated equipment agree with previous findings.

In response to the Residential Lead-Based Paint Hazard Reduction Act of 1992, the Federal government has taken a number of actions. These include the publication of Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing by the Department of Housing and Urban Development, the publication of the pamphlet Protect Your Family From Lead in Your Home by EPA and the Consumer Product Safety Commission, and the expected promulgation of EPA regulations governing training and certification of persons performing lead-based paint activities as well as a model state program. These and other actions at the federal, state, and local levels will likely increase the awareness of the potential hazards associated with household dust, and in turn persuade more homeowners and renters to sample and test household dust for lead. A standard sampling method would provide consistent interpretation of the results and uniform application of hazard remediation strategies.

1. INTRODUCTION

There is, as yet, no uniform standard for sampling house dust. Although such sampling might be considered relatively simple, more than 15 house dust sampling methods are described in the literature. This report deals with issues of standardization. It explains basic concepts, summarizes the various house dust sampling methods, and discusses different sampling strategies and their implications for meaningful and cost-effective dust collection.

Many studies in recent years indicate significant adverse effects from blood lead levels in children where these levels were previously believed to be safe. However, because the levels may not produce apparent clinical symptoms, most lead poisoning cases in the United States are undiagnosed (CDC, 1991). The sources of lead are varied. Lead in residential environments is found in soil, paint, tap water, air, food, some imported or antique cookware and ceramics, some ethnic cosmetics, folk remedies, and on some work clothes. Lead is also found in house dust.

While any single source may be the major cause of lead poisoning for a particular child, house dust is considered one of the most significant contributors to the total body burden of lead in children (Bornschein et al., 1986; CDC, 1991). Many children live in dwellings with high lead dust levels and routinely put dust-laden fingers, toys, and other objects into their mouths (CDC, 1991). Deteriorated or damaged lead-based paint and bare soil, if ingested, may also contribute significantly to children's blood lead levels. However, a more common scenario is the contamination of house dust by paint and soil and the child's subsequent ingestion of that dust.

Since lead in house dust is recognized as a major cause of lead poisoning, standardizing house dust sampling methods is a high priority for many public health researchers and regulators. From the many house dust sampling methods available, researchers or regulators must choose the most appropriate method for their specific needs. This task is complicated by the fact that results from one method may not be directly comparable to results from others. In addition, the results from the same method used in two settings may differ greatly if the sampling strategies and laboratory analysis procedures are not standardized. Hence, studies with similar objectives are being conducted in a noncomparable manner, making any form of meta-analysis questionable.[1] This situation can be expected to continue until standard methods are established.

1.1 Purpose of the Report

The U.S. Environmental Protection Agency (EPA), under Section 403 of the Residential Lead-Based Paint Hazard Reduction Act of 1992 (Title X), is developing numerical standards to protect the public from the lead hazards associated with house dust and has issued the memorandum Guidance on Residential Lead-Based Paint, Lead-Contaminated Dust, and Lead-Contaminated Soil (U.S. EPA, July 14, 1995) to serve as guidance until the promulgation of the Section 403 rule. Furthermore, proposed EPA regulations under Sections 402 and 404 of TSCA Title IV (Federal Register, September 2, 1994) and the U.S. Department of Housing and Urban Development (HUD) document Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing (U.S. HUD, 1995) specify house dust sampling as a procedure to measure lead dust hazards. To achieve these goals, however, standardized sampling methods are needed. This report is intended to proceed toward standardizing house dust sampling techniques by highlighting what is currently known about the subject.

While written for the purpose of measuring lead in house dust, many of the sampling concepts, methods, and strategies discussed here may also apply to measuring other

[1] Meta-analysis is a technique to combine the results from many studies into one single, large study.

toxicants in house dust. Ingestion of house dust is increasingly recognized as a potential contributor to the total human exposure to many substances besides lead.

The literature review described in this report is current primarily through September 1994. Readers are encouraged to consult the literature for more recent publications on the subject. Because of uncertainties in the available published information, the dynamic nature of house dust research, and the public health implications of childhood lead poisoning, the material presented here should not be assumed to be either static or totally complete. Instead, it is intended to summarize house dust sampling techniques objectively and to guide future research to retest old ideas and generate new hypotheses.

1.2 Overview of the Report

Scientists do not agree on the definition of house dust or on methods to measure it. This lack of consensus causes difficulty for those concerned with alleviating the potential hazards from ingestion of lead-contaminated house dust. The sections that follow present information compiled from both literature reviews and communication with experts.

Section 2 introduces basic concepts that readers should understand. Section 3 discusses dust lead standards and the issues involved with their development. Section 4 describes house dust and what is known about its particle size distribution, lead particle size, and sources of lead. Dusts used to test sampling equipment are also discussed. Section 5 summarizes lead dust sampling methods in two general categories: (1) wipe methods and (2) vacuum methods. Precision and accuracy performance characteristics are given for techniques when available, along with other relevant information such as the ability to sample from small areas. Section 6 briefly describes laboratory analytical techniques used to measure the amount of lead in house dust and how dust is handled in the laboratory. An overview of some fundamental issues that shape sampling strategies to measure lead exposure and potential lead hazards is provided in Section 7. Section 8 recommends criteria for selecting appropriate sampling methods, and Section 9 summarizes current lead dust research. Section 10 gives conclusions and recommendations for additional research. Finally, Section 11 contains the bibliography.

2. BASIC CONCEPTS

Two fundamentally different technologies are available to sample house dust, the wipe and the vacuum sampling technologies. Generally, wipe sampling is inexpensive, the materials needed for sampling are easy to obtain, and protocols for sample collection are simple to follow. Vacuum sampling technologies are more expensive, and sampling devices are not always easy to obtain. However, vacuum sampling may provide more information about the lead dust in a dwelling. This section discusses the major differences between the two technologies and presents several important concepts that any person reading this report should understand.

2.1 Concentration and Loading

Almost all house dust contains measurable lead concentration levels and most residential surfaces, such as floors and windowsills, contain house dust (CDC, 1991). The actual lead concentration in a sample of house dust depends on the amount of nonlead dust that is mixed with lead-containing dust. Common sources of lead-containing dust are deteriorated lead-based paint and lead-contaminated soil. The *lead concentration*, sometimes called a *mass concentration*, is usually expressed as micrograms of lead per gram of dust (µg/g) or the equivalent expression, parts per million lead by weight (ppm). The amount of dust on a surface can be expressed as grams of dust per unit area and is usually called *dust loading* (g/m^2 or g/ft^2). The lead concentration, multiplied by the dust loading on a surface, gives a *lead loading* value and is commonly expressed as micrograms of lead per unit area (µg/m^2 or µg/ft^2).[2] The dust loading and lead loading measurements are both *area concentrations*, that is,

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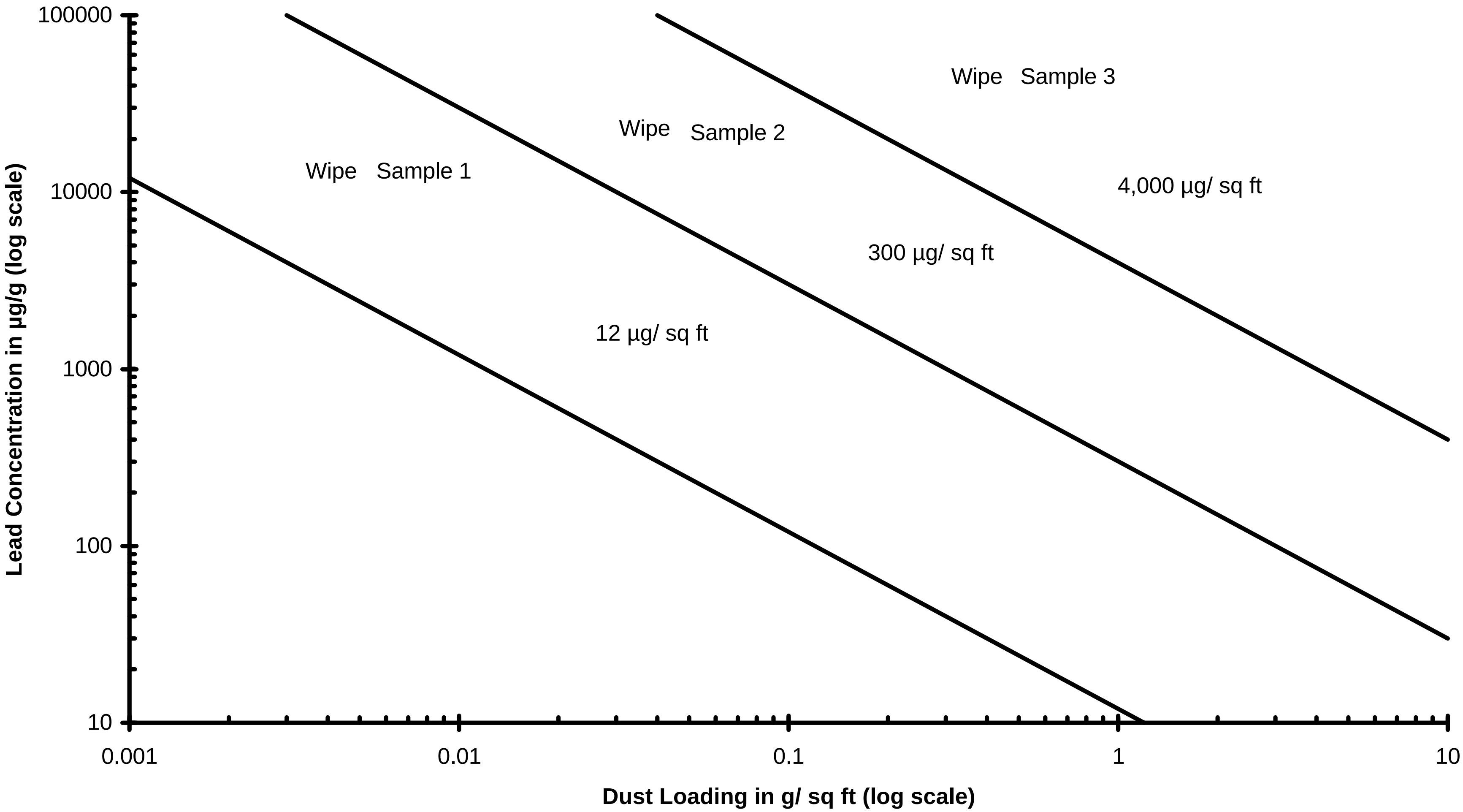
[2] Vostal et al. (1974) first used µg/ft^2 to express house dust lead loading levels. To convert µg/ft^2 to µg/m^2, multiply by 10.76. For example, 200 µg/ft^2 = 2,152 µg/m^2.

the concentration of dust or lead per unit area. In this report, "concentration" refers to mass concentration and "loading" refers to area concentration.

Common wipe sampling techniques measure lead loading directly, that is, without measuring lead concentration and dust loading. The 1990 U.S. Department of Housing and Urban Development (HUD) Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing describe the most common residential wipe sampling method, a technique that uses premoistened baby towelettes. Figure 2-1 illustrates what wipe samples can measure, using realistic results collected from floors in a hypothetical residence. Assume that each diagonal line in the figure represents the lead loading results from one wipe sample. The diagonal lead loading lines show the infinite number of lead concentration (y axis) and dust loading (x axis) combinations that might result in the measured lead loading. As mentioned earlier, the product of the two parameters is the lead loading ($\mu g/g \times g/ft^2 = \mu g/ft^2$). By using a log scale on the x and y axes, the infinite number of combinations that result in the same lead loading value fall on a straight line. Because common wipe sampling measures lead loading directly, but does not measure lead concentration and dust loading, the results from wipe sampling cannot be used to determine which combination of lead concentration and dust loading is present.

Figure 2.1 Three wipe sampling results from a hypothetical residence

Theoretical relationship among lead loading, lead concentration, and dust loading
(Diagonal lines represent constant lead loading values)



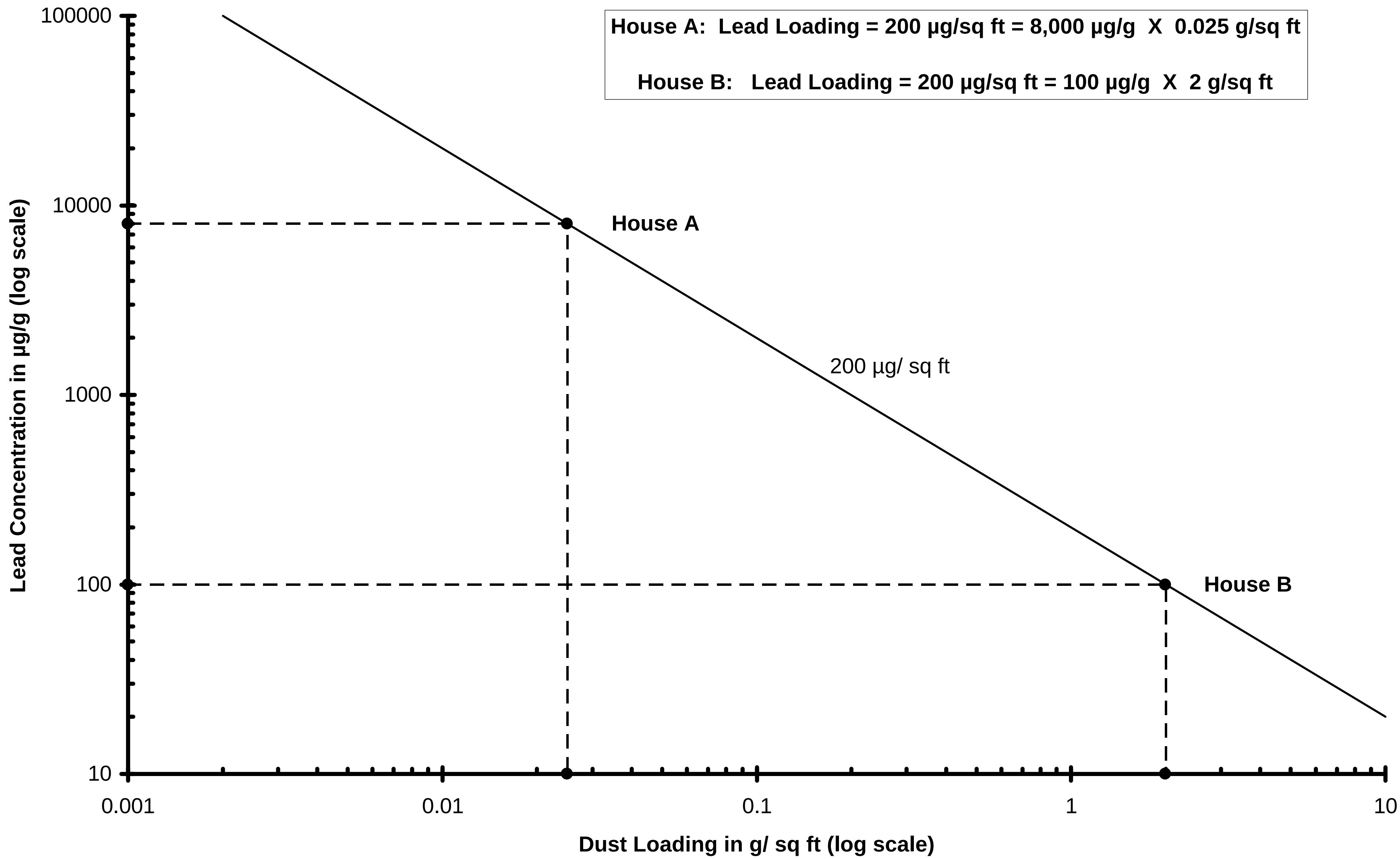
Davies (1990) states that for a given lead loading value, the lead concentration can range from high where there is little dust to, conversely, low where there is a large volume of dust. Figure 2-2 illustrates this point. In Figure 2-2, House A and House B have identical lead loading values. In House A, the floor dust has a high lead concentration, but the amount of dust on the floor, or dust loading, is low. In House B, the lead concentration is low but the dust loading is high. Although dust from House B has a low lead concentration value, the large amount of dust on the floor contains the same quantity of lead per unit area as in House A. Therefore, both houses have the same lead loading values. The only way to measure both lead concentration and dust loading is to collect a house dust sample with one of the vacuum sampling techniques, with the possible exception of the Lioy-Weisel-Wainman (LWW) wipe sampling method discussed in Section 5.1.4. Common wipe sampling methods do not measure lead concentration.

2.2 Collection Efficiency

Another important concept to understand is that the type of surface from which the dust is sampled directly affects the efficiency of dust collection from the surface. Furthermore, different sampling methods recover different amounts of total dust from the same sampled surface. These differences are due to different collection efficiencies of the methods. Roberts et al. (1991) documented total dust recoveries that ranged from greater than 90 percent by weight on a smooth painted surface to about 30 percent on a carpet. Other sampler characterization studies document similar differences (U.S. EPA, in press).

Figure 2.2 Identical lead loading values from two hypothetical homes

Theoretical relationship among lead loading, lead concentration, and dust loading
(Diagonal line represents constant lead loading value)



Three commonly cited house dust sampling methods, the University of Cincinnati Dust Vacuum Method (DVM), the Baltimore Repair and Maintenance High Volume Small Surface Sampler (BRM-HVS3), and the HUD wipe sampling method, all discussed in Section 5, may collect very different amounts of total dust from the same surface (Lanphear, 1995). Assuming that a smooth hard surface is sampled, the difference in collection efficiency between the DVM and the other two methods may be greater than a factor of 10, with the DVM sampler consistently collecting less dust than the BRM-HVS3 and the HUD wipe method. The latter two samplers would probably collect similar amounts of dust on a smooth hard surface. Since lead loading is directly related to total dust collected from the sampled surface, the DVM sampler will consistently measure lower lead loading values on hard surfaces than the BRM-HVS3 or the HUD method. This does not imply that a high collection efficiency is better than a low efficiency. An argument in favor of the DVM's low collection efficiency is that it measures the more biologically active fraction of leaded dust available to a child (Que Hee et al., 1985). However, results from the only study to use all three methods side by side in children's homes, suggest that the BRM-HVS3 and HUD wipe methods correlate slightly better with children's blood lead levels than the DVM method (Lanphear, 1995). The same study showed that the BRM-HVS3 collects much more dust from carpeted surfaces than the DVM or HUD wipe methods. The point to note is that lead loading measurements on the same surface differ among sampling methods. Further research is needed to determine the importance of collection efficiency.

Looking further at Figure 2.2, assume that the DVM collects 0.025 grams of dust from a one-square foot (1 ft^2) floor area in House A, while the HUD wipe method collects 0.303 grams of dust from an adjacent 1 ft^2 floor area, even though both areas are equally dusty. Assume also that the lead concentration in the dust is 8,000 µg/g. In this example, the lead loading measurement obtained using the DVM is 200 µg/ft^2 (8,000 µg/g x 0.025 g/ft^2). The lead loading value for the HUD method, which collects more lead dust, is 2,424 µg/ft^2 (8,000 µg/g x 0.303 g/ft^2). Since the **true** lead loading is the same for each sampled floor area, the DVM's measure of 200 µg/ft^2 is roughly equivalent to the HUD wipe measure of 2,424 µg/ft^2.

The difference in these hypothetical values is due primarily to the different collection efficiencies of each sampling method.

As with lead loading, differences in collection efficiency on different surface types and among sampling methods may affect measurements of lead concentration. Differences in the relative recovery of lead dust and nonlead dust can result in different lead concentration measurements. Theoretically, however, lead concentration measurements are likely to vary less among methods than are lead loading measurements. Results from the Lanphear study, which collected hundreds of side-by-side samples with the DVM and BRM-HVS3 methods, are consistent with this theory. Geometric mean lead levels and the corresponding standard deviations suggest that, on average, side-by-side lead loading measurements differ more among samplers than do the lead concentration measurements (Lanphear, 1995).

3. DUST LEAD STANDARDS

Under Section 403 of the Residential Lead-Based Paint Reduction Act of 1992 (Title X), EPA is developing numerical standards for assessing lead in house dust. Section 403 *Identification of Dangerous Levels of Lead* states that:

> *"...the [EPA] shall promulgate regulations...which shall identify lead-based paint hazards, lead-contaminated dust, and lead-contaminated soil."*

Lead-contaminated dust in residential dwellings is defined by Section 401 of Title X as "...surface dust in residential dwellings that contains an area or mass concentration of lead in excess of levels determined by the [EPA] Administrator under this title to pose a threat of adverse health effects in pregnant women or young children." Developing health-based house dust standards, however, will not be simple. In 1985, Duggan and Inskip stated the following in their review of childhood exposure to lead in surface dust:

> *"There are at present no authoritative and generally acceptable maximum permissible levels or guidelines or standards for lead in surface dust (neither is there agreement on methods of sampling or sample preparation). But it seems likely...that any attempt to derive such a standard might well result in a figure which is generally exceeded in many urban areas."*

3.1 Health-Based Standards for House Dust

No health-based house dust lead standard exists in the United States today. Before such a standard can be established, two general categories of lead measurements must be considered as already discussed in Section 2: lead loading and lead concentration. Although research studies have shown that estimates of both measures correlate with children's blood lead levels, it is unclear which measure is better at predicting the true, long-term, lead dust hazard to children. Results from Davies et al. (1990) suggest that the average lead loading measurements in a child's environment expressed more realistically the exposure of the child to lead than did lead concentration measurements. The authors state the following in their report:

> *"...the correlation of blood lead concentrations with lead loading in house dust (r=0.46) was much higher than for the [dust] lead concentrations (r=0.21)...Hence, the lead loading, taken over all the exposed floor surface in the rooms concerned, probably represented a better measure of exposure than the concentration."*

Results from the Lanphear (1995) study also suggest that lead loading measurements correlate better with children's blood lead levels than does lead concentration. However, the Cincinnati studies (Bornschein et al., 1985 and 1986; Clark et al., 1991) have shown that, for their conditions, lead concentration and lead loading have very similar correlation with children's blood lead levels. And Laxen et al. (1987) found that blood lead levels did not correlate better with lead dust loading than with concentration.

Even though many studies show blood lead/ lead dust relationships, few studies have attempted to derive health-based standards from the data. The Lanphear (1995) study was designed to assess the relationship between a wide range of settled dust levels and blood lead levels to identify the best sampling method for dust. Although the ranges of blood lead and lead dust levels were lower than expected, the results from this study should prove useful in the development of a standard.

Derosa et al. (1991) reviewed several studies that measured dust and blood lead and concluded that increased blood lead levels ranged from 0.2 to 7.2 µg/ dl for each increase of 1,000 ppm lead in dust. This is a wide range of values, and it likely reflects the complicated matrix of lead exposure, dust sampling and analysis, and the numerous demographic differences. It may also reflect that lead loading was not factored into the analysis. Laxen et al. (1987) derived a house lead dust concentration standard using three approaches, each with different assumptions, and proposed 1,000 µg/ g as an appropriate standard. However, Laxen studied children 6 to 9 years of age rather than younger children thought to be more at risk. He also did not consider lead loading.

Matte (1994) argues that health-based dust standards should be based solely on lead loading. He states that, while conducting health assessments based on lead loading measurements would have some limitations, there would be far less uncertainty in this approach than in current testing to assess the risk of residential exposure to other contaminants, such as radon or asbestos. He also points out that, while there is some empirical evidence to show that cleaning can, at least in the short run, reduce lead loading in dwellings, there is little or no evidence that the concentration of lead in house dust can be reduced over a short period of time. Thus, if concentration-based standards were used, many homes that "failed" such standards would presumably be considered hazardous even after interventions to reduce lead in house dust.

3.2 The HUD Post-abatement Clearance Standards

The HUD post-abatement clearance standards, adopted from the Maryland Department of the Environment's 1987 post-abatement clearance standards, are the most commonly referenced lead dust standards in the United States. It is important to recognize, however, that the Maryland standards were designed only to determine when residents could move back into a dwelling after lead-based paint abatement was finished (Farfel, 1993). They were not intended to assess the risk of lead in homes or to identify lead-based paint hazards.[3]

Maryland law requires that residents be relocated while their homes are being abated for lead-based paint, thus protecting them from exposure to high levels of lead during abatement. Before 1987, however, there was no mechanism to determine when residents should be allowed to return to their homes. Prior to the post-abatement standards, pediatric clinicians in many states recognized a high level of recurrence or new lead poisoning among children who had recently returned to lead-abated dwellings (Farfel, 1993). The Maryland post-abatement standards were established to solve this problem. Maryland developed feasible lead dust loading levels that had to be achieved by contractors after they finished abatement and before occupants were allowed to return home. HUD adopted Maryland's standards in the 1990 guidelines entitled Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing (U.S. HUD, 1990). In 1994, EPA issued guidance that lowered the clearance standard for floors by one half, while keeping the old clearance standards for windowsills and window wells (U.S. EPA, July 1994). The HUD 1995 guidelines entitled Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing incorporated the same clearance standards that EPA recommended in

[3] As defined by Title X, a "lead-based paint hazard" is any condition that causes exposure to lead from lead-contaminated dust or soil or from lead-contaminated paint that is deteriorated or present in accessible, friction, or impact surfaces, and that would result in adverse human health effects.

1994 (U.S. HUD, 1995). The current clearance standards permit up to the following lead loading levels on surfaces, expressed in micrograms of lead per square foot of surface:

Floors:	100 $\mu g/ft^2$
Windowsills:	500 $\mu g/ft^2$
Window wells:	800 $\mu g/ft^2$

The EPA and HUD have largely adopted Maryland's clearance standards and its wipe sampling approach but not its chemical analysis technique. Post-abatement clearance samples collected under Maryland law are analyzed in the laboratory after extracting part (not all) of the lead in 0.15M hydrochloric acid (HCL), a dilute acid solution. The lead extraction procedure was designed but not proven to approximate the absorption of lead in a child's digestive tract. The EPA and HUD guidelines use a wipe sampling method similar to Maryland's, but the analytical procedure calls for a "total" acid digestion of the wipe. Theoretically, total lead analysis should give more conservative, or higher, results than dilute acid lead leaching procedures. Therefore, the analytical procedure recommended by the EPA and HUD should be more protective than Maryland's. Sections 5.1.1 and 6.1 provide more information on this topic.

4. HOUSE DUST

The sources of dust, its temporal and spatial variability, and accessibility to humans, especially to young children, vary greatly from person to person, room to room, and house to house. Interpretations of house dust sample results are, therefore, affected by this variation and by the choice of sampling and analytical techniques.

Obviously, not all components of house dust are hazardous to people. Some dust sampling methods collect all particle sizes of the dust, while others are designed to collect only small particles. A few methods require sieving dust samples in the laboratory before analysis. Size-selective approaches to house dust sampling are designed to focus on the fraction of dust hypothesized to be most likely ingested by children. Public health researchers and regulators must decide what criteria are needed in selecting the most appropriate dust sampling method(s) for their needs.

This section discusses some of the selection criteria presented in the literature. It reviews what is known about the particle size distribution of house dust, the sources of lead in dust, and how real or artificial dusts are used to characterize sampling methods. Section 8 summarizes potentially important selection criteria for selected sampling methods.

4.1 Particle Size Distribution of Lead in House Dust

Vacuum cleaners pick up hair, fuzz, pieces of bugs, food, small rocks and glass, and small particles of dust, which often settle to the bottom of the bag. A significant portion of house dust consists of fine particles. Que Hee et al. (1985) found 76 percent of the total dust and 77 percent of the lead in particle sizes less than 149 micrometers (µm). (There are 25,400 µm in one inch.) Budd et al. (1990) showed that about 50 percent of the dust by weight from seven homes passed through a 150 µm sieve.

Fine dust may be the most biologically significant for the hand-to-mouth route of childhood lead poisoning (Spittler, 1993). There are several reasons for this conclusion. First, studies suggest that fine dust particles stick to a child's hands more readily than do other components of dust. Second, most research shows that lead is generally more concentrated in the fine fraction of dust. Finally, lead absorption into the body is inversely related to particle size. Thus, the smaller the dust particle, the more efficiently it is absorbed into the body. However, empirical evidence does not necessarily show that collecting and analyzing only the fine fraction of dust is a better predictor of children's blood lead levels than collecting and analyzing all particle sizes of dust. The following subsections discuss each of these issues in more detail, and Section 4.1.4 discusses the limited empirical evidence that relates particle size to children's blood lead levels.

4.1.1 Dust Adherence to Hands

The researchers Que Hee et al., Driver et al., Duggan et al., and Wang have examined dust adherence to human skin by particle size. Que Hee (1985) concluded that loose dust particles less than 246 µm, sieved from dust collected in their study houses, would be more likely to adhere to a child's hands than would larger particles and, therefore, would be more likely to be ingested by the child. In the second study (Driver, 1989), researchers examined soil adherence to skin by particle size. Driver and his colleagues dry-sieved five soil types to obtain two size fractions of particles, one less than 250 µm and the other less than 150 µm. Tests were run with the original unsieved fraction, the less than 250 µm soil fraction, and the less than 150 µm soil fraction. Results showed that an average of 0.6, 0.9, and 1.4 milligrams of soil, respectively, adhered to each square centimeter of skin on hands (mg/cm^2). An obvious conclusion from the data is that finer soil particles adhere more readily to hands than do coarser particles. Even though Driver's study was conducted with soil, it is reasonable to infer that dust particles would behave similarly.

Duggan (1985) looked at playground dust (not house dust) on the hands of school children and found that 90 to 98 percent of the particles were less than 10 µm, and the largest particle diameters were 100 to 180 µm. A review article by Duggan and Inskip in the same year states: "It follows that if the hand-mouth route is the important one for children, then there would be some merit in analyzing only those particles of diameter less than, say, 200 µm." However, young children who are crawling around indoors with wet hands in and out of their mouths would probably show a wider distribution of particle sizes on their hands than that found on the average school child. Even so, the role of particle size on hand-to-mouth contact appears substantial.

Wang (1994) also conducted a set of studies to characterize household dusts and analyzed the particle size distributions of environmental dust samples collected by vacuum, surface wipe, and hand wipe methods. Wang's results indicated that the particle size distributions of these environmental dust samplers were significantly different ($p<0.05$) than those distributions measured from hand dusts. Wang states that "the results suggest that environmental dust samples are not an adequate surrogate for hand dust retention."

4.1.2 Lead Concentration by Particle Size

Most studies that have examined lead in house dust by particle size suggest that lead concentrations in dust increase as particle size decreases. This phenomenon is well documented in Duggan's review article (1985), with numerous references for soil, street dust, and house dust. Diemel et al. (1981) exemplified this principle when they examined coarse and fine floor dust from more than 100 houses. The coarse fraction (dust resting loose on the collection filter) was analyzed separately from the filter that contained the remaining fine dust particles. The geometric mean concentration for the coarse fraction was 282 ppm, compared to 957 ppm for the fine fraction. Even though there was no information on absolute particle size, the fine fraction of dust embedded in the filter may more closely represent what adheres to a child's hands.

Results from at least two studies do not necessarily support this relationship, however. For example, Wang (1994) found that for each of seven Jersey City households where he collected dust, lead concentration levels in bulk dust, representing all dust particle sizes, were higher than the lead concentration levels for particles less than 125 µm. This finding indicates that lead was not more concentrated in the fine fraction of dust in the seven houses he studied.

Another study that examined donated vacuum cleaner bags of dust from "new" and "old" homes found that dust from the newer homes (post-1982) agreed with most of the previous studies. In this case, dust particles below 106 µm had higher lead concentrations than did larger particles. However, for dust collected from the older homes (pre-1963), lead concentrations were similar among the smaller particle size classes (<53, 53 to 106, 106 to 150, 150 to 212, and 212 to 250 µm), but the largest dust particle size class, 250 to 2,000 µm, had the highest lead concentrations (U.S. EPA, in press). The observed differences between dust from the new and old homes may be due in part to the different sources of lead dust in the environment. For example, house dust contaminated primarily by deteriorated lead-based paint may have very different characteristics than house dust contaminated mostly by soil and urban dust. However, it is not yet known how different sources of lead affect the relationship between dust particle size and lead concentration.

4.1.3 Lead Absorption and Particle Size

Toxicologists generally agree that the smaller the lead particle, the greater the absorption factor in humans. A swallowed, intact paint chip is probably much less toxic to a child than a chip that is ground into fine particles and then swallowed. Some forms of lead are also more soluble (easier to digest) than others and can be potentially more toxic to humans when ingested. While, for ethical reasons, studies of lead absorption have not been conducted on humans, they have been performed on rats. Barltrop and Meek (1979), for example, examined the relationship between lead particle size and absorption from the gastrointestinal tract of rats and found an inverse relationship between particle size and lead absorption. The relationship was most pronounced in the 0 to 100 µm particle size range. They found a five-fold enhancement of absorption with lead particles of mean size of 6 µm compared to those of 197 µm. Lead absorption from dried paint films was markedly enhanced when particle size was reduced from between 500 and 1,000 µm to less than 50 µm.

4.1.4 Significance of Particle Size on Children's Blood Lead Levels

It is often concluded from the type of scientific data presented in this section that a dust sampling method relevant to childhood lead poisoning should not collect dust particles greater than 200 to 250 µm. Some scientists believe that samplers which collect all particle sizes of dust may not provide a satisfactory measure of potential lead exposure. Furthermore, if the particle size distribution in house dust varies substantially across houses, and if small particles are more likely to be ingested, a small particle sampler or laboratory sieving procedure would, in theory, more consistently produce accurate risk estimates. However, this has not been demonstrated by empirical evidence, nor has it been extensively studied.

Only the Lanphear study (1995) has compared a sampler designed specifically to collect only small particles (the DVM sampler) with samplers that collect a wide range of particle sizes including those greater than 200 µm (the BRM-HVS3 and the HUD wipe method), and has assessed the relationship of the results to children's blood lead levels. Study results showed that the latter two samplers correlated slightly better with children's blood lead levels than did the DVM method (Lanphear, 1995).

More studies are needed to determine the significance of particle size on children's blood lead levels. Furthermore, the procedure of sieving dust in a laboratory and analyzing only the fine fraction of the dust has not been evaluated side by side with nonsieved dust to determine which technique relates more accurately to children's blood lead levels. Clearly, more research is needed in this area.

4.2 Sources of Lead in Dust

Lead in house dust comes from a plethora of external (outside the residence) and internal sources. While it is not the aim of this report to apportion sources of lead, it is important to realize that house dust includes numerous types of lead compounds that vary from house to house and from region to region (Barratt, 1990). Factors correlated with the lead concentration in house dust, as reported in the literature by Fergusson and Kim (1991) and other researchers, include the following:

- Soil and area of exposed soil;
- House age, house material, and presence of deteriorated or damaged paint;
- Distance from roads, road type, and street dust;
- Renovation, remodeling, and abatement;

- Distance from commercial garages and smelting/ mining operations;
- Dustfall rates and suspended particles indoors;
- Carpet wear and presence of a fireplace; and
- Certain parental occupations and hobbies.

4.3 Dusts Used to Characterize Sampling Methods in the Laboratory

One of the most important attributes of a suitable dust collection method is its ability, with an appropriate model, to predict blood lead levels consistently. However, sampling method characteristics are commonly reported based on laboratory studies. It is not known if a laboratory standard surface and dust can be used to assess individual methods accurately or to calibrate methods against one another with respect to their performance in homes and their relationship to blood lead levels. Furthermore, information obtained from laboratory tests alone may be difficult to interpret since real-world dust may have different physical characteristics. Nevertheless, numerous sampling method characterization studies have been performed to characterize collection efficiencies on both different surfaces and between sampling methods. The laboratory studies discussed in this section show the variation of processes used to test sampling methods and the different compositions of real and artificial dusts. All of the test methods described are well designed, but they differ significantly. Researchers do not yet agree on the best reference materials or the optimal procedures to characterize dust sampling methods.

Several researchers have characterized house dust sampling methods in the laboratory with artificial house dust. The advantages of creating a well-defined dust include the ability to control outside variability in experiments and to obtain good measures of the relative differences between sampling techniques on the substrates on which the dust is placed. However, the downside of these experiments is that artificial house dust may not represent reality -- what occurs in the laboratory may not occur the same way, or to the same extent, in one's residence. House dust is oily and sticky and has other characteristics that cannot be duplicated with artificial dust (Ewers, 1993; Roberts, 1993; and Spittler, 1993). For this reason, many researchers feel that only real house dust should be used to evaluate sampling methods in the laboratory.

Unfortunately, real house dust must be collected first, usually with vacuum cleaners, to be used as a test dust. House dust collected for testing purposes may therefore be biased toward particles that are more easily collected. As a result, any test performed on these dusts may overestimate the sampling method's ability in the field (Blume, 1993). The initial collection process may also bias the dust particle size distribution and produce an artificial dust. Real dust particles smaller than about 50 µm in diameter do not last very long by themselves after being collected by vacuum cleaners (Pella, 1993). The small particles stick to fibers and larger dust particles due to oils and to electrostatic forces generated during the vacuuming process.

Que Hee et al. (1985) collected reference dust in several houses with vacuum cleaners containing vacuum cleaner bags. The dust from these bags that passed through a 149 µm sieve was retained as loose test house dust and used to determine sampling collection efficiency of a dust sampling method these researchers designed. Dust weights of 10, 20, 30, 40, 50, and 100 mg were placed as evenly as possible on a surface and vacuumed up with the sampler. Further tests were conducted with other house dust sieved into the following six particle size fractions: less than 44, 44 to 149, 149 to 177, 177 to 246, 246 to 392, and 392 to 833 µm. These additional tests determined the sampler collection efficiency for different particle sizes on a variety of surfaces. The results from these tests are presented in Section 5.2.2.

The U.S. EPA (1989) evaluated a sampling method for Agency use using a modified American Society of Testing and Materials (ASTM) Method F608-79 originally developed to characterize the performance of commercial vacuum cleaners (ASTM, 1987). The ASTM method called for a test dust of 90 percent sand and 10 percent talc by weight spread on and embedded into a test carpet by dragging a large, smooth weight across the surface. EPA modified the test dust to "better match the reported composition of house dusts." The new mixture was 45 percent sand, 45 percent talc, 9.5 percent food-grade cornstarch, and 0.5 percent technical-grade graphite. The cornstarch and graphite particles were less than 75 µm (the size of talc was not stated in the report), while the particle size of the test sand mixture was:

- 20 percent greater than 300 µm;
- 70 percent between 300 and 150 µm;
- 2 percent between 150 and 106 µm;
- 7 percent between 106 and 75 µm; and
- 1 percent less than 75 µm.

After testing a similar subsequent sampling system, Research Triangle Institute (RTI, 1990) modified the dust to consist of 10 percent talc and 90 percent fine sand that was less than 150 µm. The same sampling method was retested by Roberts et al. (1991) with real house dust collected from carpets in six houses with an upright convertible vacuum cleaner equipped with an agitator bar. The collected dust was removed from the vacuum cleaner bags, mixed, and sieved to less than 150 µm, similar to Que Hee's approach. Approximately 15.9 g/ m^2 of this dust was added to carpets using the ASTM method, and a sampling method collection efficiency was then determined.

Midwest Research Institute (Lim et al., 1995) used artificial house dust to compare a particle separation chamber sampling method to the "blue nozzle" method (both discussed in the next section). Its reference dust consisted of three particle size classes: (1)

sand and soil with particle size less than 250 µm; (2) sand and soil 250 to 2,000 µm; and (3) sand and soil less than 2,000 µm. Crushed paint chips were added to each dust class before laboratory tests were conducted.

Farfel (1994) used artificial dusts to characterize various house dust sampling methods. Three different dusts were used: (1) a "large-diameter" dust (250-2,000 µm) made of dried sand and soil, the same as in the MRI study; (2) an "intermediate diameter" dust (38-149 µm) made from Buffalo River Sediment, NIST Standard Reference Material #2704, a soil standard; and (3) a "small diameter" dust (0.5-44 µm) made from talc.

Lioy et al. (1993) used two types of dust to characterize a wipe sampling method. These were Arizona road dust with a particle size range less than 80 µm (39%, < 5 µm; 18%, 5-10 µm; 16%, 10-20 µm; 18%, 20-40 µm; 9%, 40-80 µm) and an all-purpose potting soil, composed of organics and sand, which was dried and sieved to provide a particle size of less than 75 µm. The authors state that the sieving removed a large percentage of the sand. They used a deposition chamber to load the test dust uniformly onto different surface types. Actual house dust was not used in the experiments because hair and other materials would clog the generator and inhibit uniform deposition in the chamber.

5. LEAD DUST SAMPLING METHODS

Researchers have developed numerous innovative techniques to collect dust from surfaces. These methods range from simple wipes to high-powered vacuums and have diverse capabilities depending on the surface and its characteristics. Many of the techniques, briefly summarized in this section, are distinct from one another. Because of this, the ability to make meaningful comparisons between them is limited at best. Once again, this variability points up the need for researchers to reach agreement on standard criteria and methods for sampling house dust.

5.1 Wipe Methods

5.1.1 Vostal, Farfel, and HUD Methods

In 1973, Needleman and Scanlon hypothesized that unintentional ingestion of house dust could exceed the daily permissible lead intake in children. In 1974, Vostal et al. proposed a wipe sampling method to test the hypothesis that lead-containing house dust may cause increased lead exposures among inner city children. This sampling method, commonly cited in the literature as the Vostal Method, was modeled after a technique developed in 1962 to measure surface contamination by radioactive materials.

The Vostal Method used either disposable paper towels (14 cm x 20 cm), moistened with 20 percent denatured alcohol, or commercial towelettes. Samples were obtained by rubbing uncarpeted surfaces inside a one square foot template or on an entire interior windowsill. The researchers attempted to control the intensity and time of rubbing of every area, and to collect specimens free of paint flakes, in an effort to arrive at a standard method. Samples were collected free of paint flakes because the authors felt that flakes were not likely to be ingested by children. Their wipe samples were analyzed by soaking the towels in a dilute, 0.1 Normal hydrochloric acid solution (0.1N HCL) at room temperature, and measuring the amount of lead eluted after 10 to 15 hours. This type of analysis is sometimes referred to as bioavailable lead analysis. Section 6.1 discusses this topic further.

Vostal's results were reported as lead loadings in µg/ft^2. Quality control tests were done by wiping one area twice with separate towels and analyzing the towels separately. The authors concluded that the first wipe picked up about three-fourths of the total lead contamination on the surface. Further tests in homes showed that results from adjacent sites on the same floor did not vary by more than 20 percent, even in highly contaminated areas.

The Vostal Method, or modifications of it, has been used in numerous studies (Sayre et al., 1974 and 1979; Charney et al., 1983; Diemel et al., 1981; Matte et al., 1989) since its introduction. Farfel (1990 and 1991), from Baltimore's Kennedy Krieger Institute, used a modified Vostal Method but did not try to avoid collecting loose chips of paint which were commonly visible in window wells. He stated that the Vostal Method underestimated the total amount of lead per surface sampled because it purposefully omitted paint chips.

In Farfel's modified Vostal Method, surfaces were wiped back and forth twice in each direction, and the procedure was repeated after folding the towelette in half. Sampling efficiency was assessed by rewiping the same surfaces up to 10 times. He stated that when lead dust levels were less than 1,000 µg/m^2 (93 µg/ft^2) on an initial wipe from a smooth surface with no visible chips of paint, then either nondetectable levels of lead or levels just above detection limits were usually found on the second or third towelette. When lead dust levels were greater than 100,000 µg/m^2 (9,300 µg/ft^2) on an initial wipe, and when chips or particulates were visible, then lead dust levels greater than 10,000 µg/m^2 (930 µg/ft^2) were typically present on the 10th towelette. He concluded that sampling efficiency of a single towelette appeared to be positively related to the degree of smoothness of the surface and inversely related to the total dust on a surface.

The 1990 HUD Guidelines entitled Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing describe a wipe sampling method similar to Farfel's, except that the Guidelines called for a total acid digestion of the sample. By contrast, Farfel's modified method used 0.15N HCL, similar to Vostal. Wipe sampling results collected following the HUD guidelines should theoretically be higher than the Farfel method because of the different digestion techniques. This conclusion is supported by the recent National Center for Lead Safe Housing sampler comparison pilot study, which used both the bioavailable and the total lead wipe methods (Jacobs et al., 1993). Based on 154 side-by-side real-world wipe samples for each method, the arithmetic mean for the bioavailable method was 44.4 µg/ft^2, and the mean for the total lead method was 111.4 µg/ft^2. The geometric means were 11.1 and 15.1 µg/ft^2, and the geometric standard deviations were 4.68 and 5.61 µg/ft^2, respectively.

The Housing Authority Risk Retention Group (HARRG) and Georgia Tech also experimented with wipe samples for lead. Their digestion procedures were basically the same as HUD's, but they recommended an extra wiping pass over the sampled surface to increase collection efficiency (Sussell, 1993).

5.1.2 Preweighed Wipe Methods

The common wipe method has been modified in some cases by using preweighed wipes. Several researchers (Stark et al., 1982; Rabinowitz et al., 1985; Levallois et al., 1991; Lepow, 1974) used a preweighed wipe to collect samples and then reweighed the wipe in a laboratory. Total dust collected could be calculated by subtraction, and lead concentration could be determined after analysis (reported in µg/g or ppm). Stark et al. (1982) used preweighed cotton gauze to sample under beds and over door jambs in the study homes. Rabinowitz et al. (1985) used preweighed filter papers inside a 930 cm^2 template.

Use of pre-weighing permitted the calculation of both lead loading and lead concentration. In Rabinowitz's study, the filters were accompanied by unused filter papers because of daily humidity differences that affected the filter weights. Levallois et al. (1991) wiped 1,000 cm^2 surfaces with preweighed pieces of tissue paper. Earlier, Lepow (1974) used preweighed self-adhesive labels to measure lead in dust by pressing the labels on the surface in a single localized application. The labels were reweighed to measure total dust collected and then analyzed for lead.

An important issue that needs to be addressed when using pre-weighed wipe methods is the potential loss of sampling media or dust during the sampling and laboratory handling processes. Changes in humidity may also significantly effect the before and after weights of the samples. These potential sources of error need to be carefully controlled to make the results from pre-weighed wipe methods reliable.

5.1.3 Occupational Safety and Health Administration (OSHA) Wipe Method

In 1990, the Occupational Safety and Health Administration published a method for surface wipe sampling that was suitable for lead. The OSHA method recommends that 100 cm^2 of surface be wiped with maximum pressure in decreasing concentric squares. Wet or dry filter paper is used for collecting samples for lead. McArthur (1992), however, states that although the method is part of the OSHA *Technical Manual*, it is vague and open to interpretation. Most industrial hygienists view the OSHA wipe sampling method as useful only to qualitatively detect the presence of a contaminant.

5.1.4 Lioy-Weisel-Wainman (LWW) Wipe Method

Stern et al. (1992) and Lioy et al. (1992) briefly described the first generation of a wipe sampling device, capable of reporting both lead loading and concentration, for use on house dust contaminated with chromium.

> *"Dust wipe samples were collected using a template sampler developed at UMDNJ [University of Medicine and Dentistry, New Jersey]. The template was designed to collect dust from 50 cm^2 areas of windowsills and other surfaces using 37 mm diameter polyethylene 'draindisc' filters. Three filters were used in series to wipe the surface within the template. Two replicate samples were collected on each surface. The coefficient of variation for mass collected by the replicate samples is approximately 10%. Trial calibration studies indicated the >95% of surface mass within the template is picked up by the three filter method."*

This device, in its third generation, is referred to as the LWW wipe sampler and is described by Lioy et al. (1993). The authors state that:

> *"A flat surface wipe sampler has been developed to quantitatively measure the concentration (µg/g) and surface loading (µg/cm2) of dust on flat surfaces. The Lioy-Weisel-Wainman (LWW) Sampler has been tested under conditions that controlled particle deposition in a chamber for two types of particles: road dust and potting soil, and for three different types of surfaces: painted shelving, formica, and wood paneling. The results for replicate analyses demonstrated that the sampler had > 90% efficiency for the capture of deposited dust and had a coefficient of variation of < 20% for replicate samples of the wooden shelving and*

formica. The wood paneling had a higher coefficient of variation, although it was less than 25%, due to its porosity."

The authors describe the laboratory performance studies in detail and give step-by-step instructions on how to use the sampler. The sampler is being used in the EPA Childhood Lead Exposure and Reduction (CLEAR) study, discussed in Section 9.6, and was included in the National Center for Lead-Safe Housing (NCLSH) sampler comparison pilot study (Jacobs, 1993).

Today, a long rectangular 100 cm^2 template is typically used. But for smaller areas the 50 cm^2 template can be used. Since the template is much longer than it is wide, the 100 cm^2 fits on most windowsills. Of over 1500 wipe samples collected during the CLEAR study, the smaller template was needed less than 10 times. Comparison of LWW wipe sampling results with children's blood lead levels will be performed eventually with data from the CLEAR study. However, draft reports of those comparisons are not expected until 1996 (Adgate, 1995).

5.1.5 Dislodgeable Dust Methods

Roberts and Camens (1989) tested experimental sampling techniques to collect dislodgeable dust from carpets (surface dust likely to contact a child). These techniques were also used during EPA's House Dust/ Infant Pesticides Exposure Study (HIPES) (Fortman et al., 1991). In the HIPES study, samples were collected with a bare hand press method and a roller method. In the bare hand press method, the sampling technician pressed a hand over a prescribed area of a carpet with a pressure of approximately one pound per square inch (1 lb/ in^2). The technician calibrated the hand with a scale just prior to sampling, pressed the hand on the carpet in the prescribed manner, and then rinsed to collect the sample. In the second method, wipe sampling material wrapped on a roller that exerted approximately 1 lb/ in^2 was also used on carpets. These two techniques were designed to measure toxicants on the surface of carpets, the most likely point of contact for a child. The methods were modified for use in an EPA nine-home lead study, described in Section 9.12.

5.1.6 Dust Fall Methods

While not directly germane to this report, dust fall plates have been used in a number of studies to passively measure lead in suspended dust as it settles. The plates are usually placed in out-of-the-way places, such as on top of a refrigerator, for long periods of time, such as one month (Seifert et al., 1984 and U.S. EPA, 1991). The amount of dust that settles on the plates can be weighed, and a dust fall rate can be calculated. Total lead on the plate can also be analyzed to determine the lead fall rate. This information may facilitate estimates of lead deposition on toys and food surfaces in a home and may also help assess the lead inhalation exposure route. However, it is not known if dust fall measured in out-of-the-way-places reflects dust fall on surfaces where children are exposed. Dust settling mats have also been used to measure lead that is tracked into a residence (Elias, 1994).

5.1.7 Wipe Comparison Studies

Chavalitnitikul and Levin (1984) compared several types of wipes. They conducted a laboratory wipe sampling experiment with wipe materials on a smooth Formica surface and a plywood (rough) surface. The study examined different wipe materials, such as Whatman filters, paper towels, and adhesives -- paper labels, adhesive cloth, and dermal adhesive. The researchers determined that, on smooth surfaces, all techniques were comparable, with about 85 to 90 percent recovery with carefully prescribed protocols. On plywood, however, recoveries dropped to less than 43 percent, with the adhesive samplers performing better than the wipes. They also noted that the Whatman filters fell apart on the rough surface.

Researchers from the National Institute for Occupational Safety and Health (NIOSH) examined several different wipe materials both in the laboratory and in the field. Millson et al. (1994) evaluated SKC® filter paper, Johnson & Johnson® gauze pads, Wash'n Dri® hand wipes, and Wash-a-Bye Baby® baby wipes in the laboratory with NIST standard reference materials (SRMs). Their selection of wipe materials was based on the following experience:

> *"Several commercially available materials that could be used to collect wipe samples for lead were obtained from drug stores in a variety of locations in the United States. Initially, these wipes were chosen arbitrarily, but several (i.e., wipe materials containing aloe) were found to have high background lead levels (>5 µg) and/or left large amounts of residue following digestion."*

The NIST SRMs used to measure percent lead recovery following acid digestion were lead-based paint (SRM #1579), urban dust (SRM #1648), and Buffalo River sediment (SRM #2704). The wipe materials were spiked with known quantities of the SRMs and digested by two different analytical procedures: (1) a nitric acid/ perchloric acid hot plate extraction and (2) a nitric acid/ hydrogen peroxide hot plate extraction. The researchers found that recoveries for the spiked wipes were statistically equivalent (p=0.05) between the two digestion techniques.

Sussell (1993), also at NIOSH, used the individually wrapped Wash'n Dri® hand wipes according to NIOSH Draft Method 0700 (Eller, 1993) in a building heavily contaminated by deteriorated lead-based paint. Sampling from this method was prescribed inside a 10 cm x 10 cm plastic template cut from an 8 and 1/ 2" x 11" overhead transparency, and secured with masking tape. The sampling technique called for unfolding the wipe, then folding it to one-fourth its total size. The surface to be sampled was wiped with firm pressure, using four vertical S-strokes. The exposed side of the wipe was then folded inward, and the same area was wiped with four horizontal S-strokes. The wipe was folded once more, to expose a clean portion, and the area was wiped again with four vertical S-strokes. The wipe was then folded, exposed side in, and placed into a new sealable plastic bag.

Sussell and colleagues conducted a brief study using this method, as part of the overall investigation to estimate the sample variability of surface wipe samples. The authors collected six sets of five side-by-side wipe samples on floors in an unoccupied institutional building heavily contaminated with deteriorated lead-based paint. The results showed considerable variability among the side-by-side samples. Relative standard deviations (RSD) ranged from 44 to 69 percent for samples with lead loadings between 1,351 and 8,417 µg/ ft^2. The quintuplet sample with the lowest average lead loading (725 µg/ ft^2) had a RSD of 17 percent.

5.2 Vacuum Methods

5.2.1 Commercial Vacuum Cleaners

Commercial vacuums are frequently described in the literature as research lead dust samplers. Many researchers have collected samples from homeowners' vacuum cleaners, some stating that they sampled only the fine dust that settled to the bottom of the bag (Kaye et al., 1987; Moffat, 1989; Thornton et al., 1990; Davies et al., 1990; Jensen, 1992). Diemel et al. (1981) and Watt et al. (1983) modified their vacuum cleaners to hold filters. Roberts et al. (1987) characterized collection efficiency for different vacuum cleaners with new preweighed vacuum cleaner bags with the modified ASTM method F608-79 mentioned in Section 4.3.

Roberts et al. (1989-1990) also did studies on the differences in using vacuums with or without carpet agitators. His studies suggest that vacuums with agitators pick up from two to six times more dust from a rug than other vacuums. In other laboratory tests by Roberts, using a commercial upright vacuum cleaner with a power-driven agitator, the recovery of fine particles (<150 µm) was less than 2.3 percent of the fine dust, by weight, applied to carpets. The authors stated, after the tests, that much of the dust could not be removed from the bag where most of the fine dust was collected. Decontamination of the agitator unit was also complicated.

Spittler (1993) and Roberts (1993) state that grab samples collected from a home vacuum cleaner can be an effective screening tool to determine high-risk households. However, no blood lead data is available to either support or refute these interpretations. Spittler, from the EPA Region I Laboratory, has provided assistance and advice on lead hazards to hundreds of private citizens for many years. He instructs people concerned about lead dust levels in their houses to send him several grams of fine dust collected from a vacuum cleaner bag. He measures lead concentration (µg/g) in the dust and offers recommendations to homeowners based on his extensive experience.

Finally, Camann and Lewis (1990) used a commercial vacuum cleaner to collect and analyze house dust for pesticides. Their vacuum filtered air through water before it was discharged back into the room, after which the water was analyzed for the pollutant. The usefulness of this method to measure lead in house dust is not known.

5.2.2 University of Cincinnati (DVM) Method

A house dust sampler constructed from common industrial hygiene sampling materials was first cited by Que Hee et al. (1985). The sampler was developed by Peace, the second author in Que Hee's paper, for a large prospective epidemiological study started in

1980 (Ewers, 1993). The sampler consists of a common personal air-monitoring pump, usually operated today at 2.5 to 3.0 liters per minute (Lpm) but evaluated in the 1985 study up to 2.0 Lpm. The pump is connected to a three-piece air-monitoring cassette containing a 0.8 µm polycellulose acetate filter. A small crimped stainless steel tube or clear plastic nozzle (with an opening approximately 1.3 cm x 0.1 cm) is usually attached to the inlet side of the filter cassette via Nalgene Tygon® tubing. It has also been used with a nozzle made from a short piece of Tygon® tubing cut at a 45 degree angle.

The sampler was specifically designed to collect only dust that would most likely stick to a child's hands, not total lead on a surface. Hence, its collection efficiency drops significantly for particles larger than 250 µm. The collection efficiency, as determined in laboratory tests with real house dust, is 62 percent for particles less than 44 µm, 76 percent for particles 44 to 149 µm, 71 percent for 149 to 177 µm, 47 percent for particles 177 to 246 µm, 5 percent for particles 246 to 392 µm, and 14 percent for particles 392 to 833 µm. This sampler has been used in numerous studies, and its use has probably amassed the largest database linking lead in dust to lead in children.

The University of Cincinnati has used a clear plastic nozzle for its method so that the person sampling can see when the nozzle is plugged with dust or other material. If the nozzle is plugged, the material is pushed into the sample cassette with a small pointed object; then sampling continues. Plastic nozzles, in contrast to stainless steel, are also disposable, and decontamination between samples is unnecessary. A quote from the sampling protocol in a University of Cincinnati study (Butte-Silver Bow, 1991) states the following:

> *"If the floor is carpeted, an adequate sample can readily be collected from almost any pathway in the room. A pathway might consist of an area immediately inside of a doorway into a room or an obvious pathway from one side of the room to the other. In rooms where there is no carpeting,*

the most likely place to find an adequate supply of surface dust might be an area immediately adjacent to a wall. Very often on floors with hard surfaces, dust will migrate to the edges; therefore, that is the most likely place to collect the dust."

In recent years, sampling areas with this method are usually defined inside a 25 cm x 25 cm plastic template. A three-sided template is commonly used on bare floor to vacuum dust that has migrated to the walls (Menreath, 1991). Sampling areas are normally covered with three passes. The University of Cincinnati protocol calls for a visible amount of dust on the filter to collect a quantity adequate for the prescribed analytical method. Typically, more than 5 minutes is required to cover one 25 cm x 25 cm area.

In addition to the University of Cincinnati prospective study, this sampler was used in Cincinnati during the EPA Three City Urban Soil-Lead Demonstration Project (U.S. EPA, 1991). It was also used in the Center for Disease Control / National Center for Environmental Health (CDC/NCEH) and National Institute for Occupational Safety and Health (NIOSH) FBI Take Home Lead Study (NIOSH, 1994), the NCLSH sampler comparison study (Jacobs et al., 1993), the NIOSH Take Home Study (Whelan et al., 1994), and the Lanphear study (1995). In this last study, the clear plastic nozzle was replaced with Tygon® tubing cut at a 45-degree angle to avoid possibly plugging the nozzle during use.

One common concern about this method is the laboratory measurement protocol for weighing total dust collected, especially if the weights are low. This issue is discussed in more detail in Section 6.2. In relation to other vacuum samplers, however, the DVM method has been used the most and much of our knowledge about dust/blood lead relationships in children comes from studies that used the DVM sampler.

5.2.3 Sirchee-Spittler Sampler

The Sirchee-Spittler sampler is a hand-held, battery-powered vacuum unit designed to collect forensic evidence. This sampler was used in Boston and Baltimore during EPA's Three City Urban Soil-Lead Demonstration Project. (The DVM sampler, mentioned earlier, was used in the third city, Cincinnati.) Dust is collected inside a removable cup with a fine mesh stainless steel screen that removes the dust from the vacuumed air. It is assumed that while fine dust particles are initially discharged through the screen, after several seconds of operation dust particles and fibers catch on the screen and increase the sampler's collection efficiency for fine particles (Spittler, 1993). However, the sampler's collection efficiency, relative to particle size and to other dust samplers, has not yet been determined because it has not been included in any of the method comparison studies. The coefficient of variation was 15 percent for lead concentration measurements as calculated from side-by-side duplicate composite samples from several homes (Rinehart and Yanagisawa, 1993).

Dust collected from the Sirchee-Spittler sampler is generally transferred into labeled-reinforced paper envelopes, folded and taped shut, for transport to the laboratory. The analytical procedure requires sieving samples through a 250 µm sieve, before the dust is weighed, to remove large debris and hair, and possibly to retain the particles most likely to adhere to a child's hands. The sampler is simple to use, highly portable, and can cover large areas in a short period of time.

5.2.4 Blue Nozzle Method

The Blue Nozzle method was developed by MRI for the HUD-sponsored National Survey of Lead-Based Paint (MRI, 1991). The sampler consists of a laboratory 110 volt rotary vane pump connected to the same filter and sampling cassette used in the University of Cincinnati method, via thick-walled 3/8" Tygon® tubing. The cassette is used with a specially designed angle-cut blue Teflon nozzle, 4" long x 2" wide, that fits over the cassette with O-rings to seal it. The blue nozzle name was coined for the color of the nozzle. The large nozzle allows sampling areas to be covered in fewer passes than required for the DVM method, thus, reducing the time spent in dwellings. The sampling flow rate is cited as 16 Lpm. (Solomon and Hartford (1976) first used a laboratory rotary vane pump to collect dust samples.)

5.2.5 HVS Series

The EPA's Office of Research and Development in Research Triangle Park, North Carolina has funded the development of a cyclone house dust sampler. The HVS2 (High Volume Surface Sampler) was originally developed to measure pesticides in house dust (Budd et al., 1990; U.S. EPA, 1989; Roberts et al., 1989 and 1991). The HVS2 is a high-powered vacuum cleaner equipped with a nozzle that can be adjusted to a specific static pressure and air flow rate to allow for consistent dust collection. Approximately 30 percent by weight of particles less than 150 µm were collected from the surface when sieved, real house dust was ground into either plush or level loop carpets by the ASTM Method F608-79. Recovery was greater than 90 percent by weight from a smooth, hard surface. Once dust was inside the cyclone, particles greater than about 5 µm were removed from the air stream and collected. Smaller particles were not collected by the cyclone but were caught by a high efficiency quartz fiber filter placed in line to the exhaust airstream. Tests have shown that the cyclone removes and retains more than 99 percent by weight of average house dust, with less than 1 percent discharged onto the filter.

To make the device lighter and more maneuverable, the HVS3 was developed using the same cyclone (RTI, 1990; Roberts et al., 1991; Fortman et al., 1991a and 1991b; Lewis et al., 1991), but without the quartz fiber filter. The manufacturer states that the HVS3 will collect a large, representative sample of house dust from indoor surfaces, such as rugs and bare floors, and dust from outdoor surfaces, such as streets, sidewalks, lawn, and bare, packed dirt. It has been used to assess risks from lead and pesticides in house dust, but its use is limited to floors or other large flat surfaces because it cannot reach small or uneven areas, such as windows and upholstery.

Lewis (EPA/ ORD) modified the HVS3 by adding an attachable small wand to allow it to sample other areas (Lewis, 1993). A new ASTM standard, ASTM D 5438-93, "Standard Practice for Collection of Dust from Carpeted Floors for Chemical Analysis" (ASTM, 1993) was recently passed and describes a standard method for the sampler's use.

5.2.6 CAPS Cyclone

The EPA and Midwest Research Institute (MRI, 1992; Lim et al., 1995) developed a portable, AC-powered particle separation chamber sampler (similar to a cyclone) from standard PVC pipe and pipe fittings and a commercially available handheld vacuum. It is designed to be an inexpensive vacuum sampler constructed from materials commonly found in hardware stores. This sampler was characterized by the MRI Engineering Study to Explore Improvements in Vacuum Dust Collection and used in the EPA Comprehensive Abatement Performance Study (CAPS), both described in Section 9. Its name originates from the CAPS study.

5.2.7 BRM-HVS3 Method

Farfel, from the Kennedy Krieger Institute, has experimented with a modification of the HVS3, using the same cyclone as in the HVS3 but with the portable handheld vacuum that MRI used for the particle separator. Rigid PVC and then, after further modifications, flexible tubing was attached to allow small areas to be vacuumed. The original

HVS3 operates at 20 cubic feet per minute (cfm) through the cyclone; the handheld vacuum pulls about 15 to 15.5 cfm wide open and unobstructed. The flow rate may decrease during use because of resistance from the surface, but the particle size removed by the cyclone (and not discharged into the room) should not change significantly because of its design (Hirsh, 1993). Farfel's protocol analyzes total dust collected by the cyclone. Since this method is currently being used for the EPA Baltimore Repair and Maintenance Study, the sampler has recently been called the BRM sampler to differentiate this modification of the HVS3 from the original HVS3.

5.2.8 Prpic-Majic Method

Prpic-Majic (1992) introduced a vacuum technique different from any described earlier. The sampler is a vacuum pump with a screen at its entrance that prevents coarse particles and small objects from being collected on the membrane filter that serves as the sampling surface. Total dust measurement was obtained from the dust particles that reached the filter. There was no mention of potential loss of fine dust trapped in the prescreen, especially after it was loaded with fibers.

5.2.9 Lioy's Vacuum Method

Lioy has developed a sampler powered by a small canister vacuum rated at 6.5 amps at 65 cubic feet per minute. This device is being used in EPA's Childhood Lead Exposure and Reduction (CLEAR) study to sample dust from carpets. A small, in line, conical-shaped filter collects the dust. The preweighed filter is located downstream from the pickup nozzle in the vacuum hose. After sampling, the filter is removed and reweighed to measure total dust collected. Results from using this sampling method are not currently available.

6. LEAD DUST ANALYSIS

Laboratory analysis is an important factor in comparing the results from different house dust sampling methods, in the overall cost of the dust sampling project, and in the development of meaningful house lead dust standards. Approaches to lead dust analysis are briefly summarized in this section, along with information on how dust samples are handled in the laboratory. The purpose of this section is to give the reader a flavor of the many approaches involved. It is not meant to be a comprehensive review of laboratory protocols or to give guidance to laboratories conducting house dust lead analyses.

As discussed in Section 2, the amount of lead in house dust is expressed in two ways. Lead concentration measures how much lead is **in the dust**. Lead loading measures how much lead is **on a surface**. To recapitulate the previous discussion, the units of measure are:

1. *Lead concentration* -- micrograms of lead per gram of house dust (µg/g) or the equivalent expression -- parts per million lead (ppm).

2. *Lead loading* -- micrograms of lead per square foot of surface (µg/ft^2), equals lead concentration in dust multiplied by the amount of dust in a given area (µg/g x g/ft^2).

When a chemist analyzes house dust for lead, the results are first expressed as micrograms of lead per sample (µg/sample). If the sampled area was measured in the residence, then a simple calculation can be applied to express the result as a lead loading (µg/ft^2).

- Micrograms per sample **DIVIDED** by the sampled area in square feet equals µg/ft^2.

To calculate lead concentration (µg/g), one must know the total sample weight of the dust analyzed by the laboratory. Total dust weight is needed to convert micrograms of lead per sample to micrograms of lead per gram of dust.

- Micrograms per sample **DIVIDED** by the grams of dust analyzed equals µg/g.

6.1 Analytical Laboratory Techniques

There is at this point no agreement in the research community on the best analytical laboratory techniques to measure lead in house dust. The literature cites many different approaches. Some researchers measure total lead, while others measure only leached lead, which is a fraction of the lead extractable from samples. Since lead-leaching procedures may more closely approximate lead that is likely to be absorbed into the body on ingestion, this type of lead has been referred to as bioavailable lead in the literature. Using this name, however, implies that bioavailability can be measured, which may not be possible.

The most commonly used laboratory instruments to quantitate total or leached lead from dust are inductively coupled plasma atomic emission spectrometry (ICP-AES), flame, or graphite furnace atomic absorption spectrophotometry (FAAS or GFAA), and energy dispersive X-ray fluorescence (XRF). The ICP, FAAS, and GFAA instruments require wet chemical sample extraction procedures, such as acid digestion or leaching, before samples can be analyzed for lead. The wet chemical extraction procedure dictates whether ICP, FAAS, or GFAA measures total or leached lead. Samples for XRF analysis do not require sample digestion. Most XRF lead dust analytical procedures only require sieving samples to less than 250 µm or 150 µm before analysis.

The purpose of a sample digestion procedure is to pull the lead out of a solid matrix -- dust in this case -- and draw it into a solution that can be analyzed by ICP, FAAS, or GFAA. Total digestion procedures pull more lead into solution than do leaching procedures. True "total" lead is determined only when hydrofluoric acid is added to the mixture because it breaks apart crystal structures (silica) in the dust and theoretically releases all of the bound lead into solution (Barratt, 1990). However, "total" lead is also commonly used, as in this report, to refer to any procedure that digests dust in strong acids on a hot plate or in a microwave oven. Hot acid digestions for lead dust are usually modifications of EPA SW-846 Method 3050 and NIOSH methods 7300, 7082, and 7105, which require hot nitric acid extraction, nitric acid/ perchloric acid extraction, or nitric acid/ hydrogen peroxide extraction (Eller, 1984; Millson, 1994). Still other researchers have used hydrochloric acid and aqua regia (Duggan and Inskip, 1985).

Other potential analytical methods are documented. A new ASTM standard analysis method, for example, will be available soon, based on NIOSH and EPA/ ORD-RTI digestion procedures (Ashley, 1994). The EPA published another standard operating procedure titled "SOP for Lead in Paint by Hotplate- or Microwave-based Acid Digestions by AA or ICP" in 1991. All of these protocols (EPA, NIOSH, and ASTM) have been found to perform well in the Environmental Lead Proficiency Analytical Testing (ELPAT) program administered by the American Industrial Hygiene Association. This program, which is a collaborative effort between the CDC, NIOSH, and EPA/ Office of Pollution Prevention and Toxics (OPPT), is designed to evaluate and improve the performance of laboratories conducting analysis associated with lead hazard identification and control activities (Schlecht and Groff, 1994).

Laboratories that successfully participate in the ELPAT program and pass a systems audit may be recognized by the EPA National Lead Laboratory Accreditation Program (NLLAP). The NLLAP provides federal oversight for state and private sector laboratory accreditation programs for laboratories analyzing paint, soil, and house dust samples associated with the identification and control of lead-based paint hazards in housing. A list of EPA recognized laboratories is available from the National Lead Information Center Clearinghouse, by calling 1-800-424-LEAD.

Leached-lead samples are extracted by soaking dust samples in dilute acid (usually HCL) at room temperature for a specified time to leach the lead into solution. The purpose of leaching is to measure bioavailable lead only, the lead that is likely to be extracted by the stomach. There is no agreement, however, on how the unknown fraction of lead ingested and then absorbed by the body should be measured. Lead absorption by humans is complex and not completely understood. Factors such as the lead particle size, the chemical form of lead, diet, and the age all play a role.

The most commonly used lead-leaching procedure was described by Vostal and Sayre in 1974 (also described briefly in Section 5.1.1). In the Vostal Method, wipe samples were soaked in 0.1 N hydrochloric acid for 10 to 15 hours. Farfel (1990 and 1991) and other researchers have also used this process, sometimes with slight variations in the strength of hydrochloric acid. Rabinowitz (1985) soaked wipes in perchloric acid (pH 1.8) "to extract the leachable lead, which is considered to represent the bioavailable portion better than the total lead content." Levallois (1991) soaked samples in 10 percent nitric acid for 1 hour before analyzing the solution. Duggan and Inskip (1985) cite two studies in their review comparing the results obtained with total extractions to a 0.07 N HCL leaching method. The ratio of total lead over bioavailable lead ranged from 1.3 to 2.1.

As mentioned earlier, several digestion procedures exist to measure total lead. Variations in results among the different total lead digestion procedures, however, are not great, and Que Hee (1985) notes this in his work. Unlike most total digestion procedures, which give fairly consistent recoveries near 100 percent, differences in lead-leaching procedures may vary among methods. Further work is also needed to compare wet chemical procedures to laboratory XRF techniques because results between the two can vary from 25 to 30 percent (Pella, 1993).

Finally, the mass of many samples submitted to a laboratory will be too large for a single sample digestion step in preparation for instrumental analysis. For these large samples, to obtain an accurate analysis, the laboratory must either homogenize the samples and analyze an appropriate subsample, or analyze the total sample by multiple subsample digestions, compositing the digested subsamples for a single instrumental analysis. In any case, it is critical that the methodology used be tested by the laboratory as appropriate, not only for the matrix (e.g., dust wipe) under consideration, but also for the range of sample sizes being submitted for analysis.

6.2 Dust Handling Concerns in the Laboratory

After house dust samples are collected, a potential source of error lies in how the dust is handled prior to analysis. To determine lead dust concentration (µg/ g or ppm), it is necessary to weigh the amount of dust collected. This is difficult, if not impossible, using some sample collection methods. Wipe samples, for example, should not be chosen if concentration measurements are to be made, although the LWW wipe method may be an exception. With wipe samples it is difficult to obtain reliable tare weights. The weight of dust wiped from the surface is generally small compared to the weight of the wipe, making accurate dust weights difficult to measure.

Sampling methods that collect dust in small plastic cassettes require careful handling to determine accurately the total dust weight and then quantitatively transfer the dust collected to digestion glassware. The University of Cincinnati DVM method (Que Hee et al., 1985) requires rinsing the dust with water from the sample cassettes into preweighed 50 to 100 milliliter glass beakers to obtain a total weight. The water is then evaporated and the beakers are cooled and reweighed on a balance. Research on this technique has been continued by the Hematology and Environmental Laboratories of the University of Cincinnati and it has been determined that 2 milligrams (mg) of dust collected in the cassette is the minimum that can be accurately weighed (Roda, 1994). Roda also stated that the average weight of dust collected by the DVM method and analyzed by the laboratory is approximately 50 mg. Researchers at NIOSH, who have analyzed DVM samples collected by industrial hygienists, have used preweighed filters in the sample cassettes and reweighed the filters after sampling to obtain total dust weight. However, dust may cling to the side of the cassette because of the low sampling flow rate and static electricity forces. This may create a problem for the laboratory technician who must quantitatively transfer all of the dust from the cassette, with the filter, to the balance to get an accurate weight. It should be noted, however, that Que Hee et al. (1985) carefully document the development of the DVM method and, for their purposes, conclude that filter weighing is not necessary.

Another technique that has been used with the DVM method is to tare weigh the entire filter cassette before sampling. With this procedure, however, the cassette cannot be handled with bare hands in the field or laboratory due to the potential deposition of hand oils that could affect the total weight and introduce error. Another potential problem with preweighing cassettes is that the commonly used polycellulose acetate filters are highly hygroscopic (retaining moisture), and weights may fluctuate greatly. PVC filters, which are much less hygroscopic, should be used if cassette weighing is used.

Still other methods, such as the Sirchee-Spittler method and the original HVS3 method developed by Roberts, specify sieving samples in the laboratory. Potential problems with sieving include cross contamination, particularly just after highly contaminated samples are analyzed, and general sample loss due to the extra handling of the dust. Samplers also may collect more dust than is needed for analysis. Biased lead results may occur if the laboratory technician is not careful to collect representative subsamples for analysis.

The BRM-HVS3 laboratory protocol is designed to minimize handling losses by using a tared microwave digestion vessel as the dust collection cup. After sampling, the cup is removed, sealed, and sent to a laboratory. When the sample arrives in the laboratory, a final weight is obtained to measure total dust collected. Then the digestion reagents are added directly to the digestion vessel, and it is microwaved. This protocol eliminates dust handling and transferring procedures.

Vacuum sampling errors due to weighing, sieving, and other dust handling steps in the laboratory are not distinguished from total measurement errors unless known dust standards and other quality control checks are designed to measure them. Quality control often comes later in the analytical process (e.g., during acid digestion). Whether any of these sources of laboratory error are excessive compared to sampling error depends largely on how the dust sample arrives at the laboratory, what needs to be done to it, and the skill and patience of the chemist. If a measurement of lead concentration in dust is important to obtain, sampling methods that present the dust in an easy-to-handle form should be considered over alternate methods.

7. SAMPLING STRATEGIES

Choosing an appropriate sampling method is an important part of designing a study to measure lead in house dust, but it is only one part of a more complicated sampling and decisionmaking system -- the sampling strategy. While the sampling method specifies how to collect a sample of dust from a surface, a sampling strategy specifies the **process** of sampling that includes the following:

- Which surfaces and substrates should be sampled,
- When and how sampling should take place, and
- Whether a composite sample should be created.

Before deciding on a sampling strategy, it is important to determine the goals to be achieved. A specific goal may be to assess children's lead dust exposure in their daily environments. This is called an exposure assessment and reflects concern at the individual level. Another goal may be to identify lead-based paint hazards in housing so that gross lead sources can be reduced. This goal, called primary prevention lead risk assessment, includes preventing children from becoming lead poisoned but on a more global level. Different sampling strategies may be appropriate for different situations.

After the goals are defined, the potential effect of the substrate on dust collection should be factored into the design of a sampling strategy because dust collection efficiencies from different surface types can vary greatly. Other considerations, such as composite sampling, should also be addressed. Composite sampling is a technique which yields the average lead measurement of two or more samples by physically combining the samples in the field into one sample. One major impetus for composite sampling is to lower costs by reducing the number of samples that need laboratory analysis.

Substrate effect, composite sampling, and the two different sampling goals mentioned earlier, exposure assessment and residential lead risk assessment, are described in this section. Section 7.1 discusses the substrate effect on dust sampling and suggests approaches to control it. Section 7.2 discusses composite sampling strategies and how they can be used to reduce costs. Section 7.3 provides an overview of exposure assessments and proposes a strategy to estimate the average house lead dust levels to which a child is actually exposed, based on a specific pattern of activity during the day. Finally, Section 7.4 discusses primary prevention lead risk assessments and how strategies can be designed to determine and report on the existence, nature, severity, and location of lead hazards in housing.

7.1 Substrate Effect on Sampling

Studies of sampling recoveries using different sampling methods indicate different dust collection efficiencies on different surfaces (U.S. EPA, in press). Large differences in recoveries have been found between smooth surfaces and carpets, between different types of bare surfaces (smooth and rough), and between different types of carpets (short pile and shag). Moreover, sampling on carpets generally collects both carpet fibers and dust.

House dust on a floor or a carpet can be classified on a scale from loose and easy to collect to bound to the surface. On hard floors, the smaller particles may be more likely to be bound to the surface than the larger particles, especially when the surface is rough (e.g., wood or cement). For carpets, some dust particles may reside on the surface of the carpet, while others may be among the fibers or near the base of the carpet. While the physical variability of dust loadings and lead concentrations across a room has not been thoroughly investigated, noncarpeted areas with less disturbance or traffic, such as areas at the edge of a room, may accumulate more **loose** dust, on average, than areas that are often disturbed with foot traffic. High-traffic areas may have more ground-in dust, however. Separate samples collected from these two areas within the same room may give very different lead results. Carpeted areas may exhibit different characteristics from hard surfaces because loose dust may not migrate from high-traffic areas to low-traffic areas as it would on hard floors. Therefore, the highest dust loadings in carpets may be found in the high-traffic areas. Unfortunately, no studies have been specifically designed to assess these issues or to determine the magnitude and importance of lead loading or concentration variability across floors.

The amount of dust ultimately collected using a chosen sampling method depends largely on the design of the collection equipment, the effort involved in sample collection, and the distribution of the dust by both particle size and how well the particles are bound to the surface. An ideal sampling method collects dust with characteristics similar to the dust normally ingested by a child, including childlike dust pickup characteristics on different surfaces and in different locations that match a child's movements. In this ideal situation, if the child picked up half as much dust per unit area on a carpet as on a floor, the sampling method would do the same.

Lead loading or lead concentration measurements from one sampling method may correlate well with blood lead levels when dust is collected on hard floors or on carpets. However, if the child's relative consumption of dust from floors versus carpets is different than the sampling method's relative collection efficiency on these surfaces, the relationship between blood lead levels and lead dust levels will be different for each surface. Because the amount of dust contributed from different surfaces and ingested by a child is not known, it may be appropriate to design a study to collect separate samples from bare floors and from carpeted areas. After this is done, regression or other statistical techniques could be used to determine the relative contribution of floor dust and carpet dust to blood lead levels. Based on the statistical results, it may be possible to design sampling strategies to collect samples from different surfaces in a manner that more closely mimics the dust ingested by a child. Alternatively, samples could be collected from different surfaces, and a weighted average of the measurements on each surface type could be used to predict blood lead levels. The weights would depend on the areas frequented by the child, and the time a child spends in these areas.

7.2 Composite Sampling Strategies

Many studies have collected numerous dust samples in homes and analyzed each one separately. Still other studies have composited several dust samples from different locations inside a home into one or few samples (Farfel and Rohde, 1995). A potential advantage of composite sampling over single-surface sampling is that large areas of a dwelling can be sampled with the cost of only a few laboratory analyses. As mentioned earlier, however, little research has been done to examine the variability in lead dust loadings or concentrations across a floor within a room and between different rooms of a dwelling. Thus, it is not clear if sampling from one location (e.g., one-square foot) is sufficient to characterize the lead dust levels in other locations. Assuming that variability among locations is great, composite sampling, which provides an average of lead levels across the subsampling locations, may provide a cost-effective means of reducing the variability in lead dust measurements due to spatial variation in the distribution of dust.

The lead dust that affects a child may be thought of as a weighted average across the areas where the child has dust contact, with weights roughly proportional to the time a child spends in different areas of the home. From a sampling perspective, the average lead loading to which a child is exposed to may be estimated by collecting many individual samples for separate analysis and combining the results by calculating a weighted average after analysis. Or, as mentioned earlier, field composite samples can be collected before laboratory analysis by collecting and physically combining two or more dust samples from each of several areas in a dwelling. Researchers have used both strategies for collecting dust samples.

A common criticism of composite sampling is that lead variation across a floor or home cannot be determined; lead hot spots may be missed. It must be acknowledged, however, that **any** sampling strategy will miss hot spots. The important question is how much these hot spots contribute to the total exposure of the typical mobile child. This question has not been answered by scientific studies. The statistical relationship between blood lead levels and the estimated average lead intake across children's contact areas may be a better predictor of exposure than the relationship between blood lead levels and a high lead exposure for a short period of time, such as from a lead hot spot. From a theoretical point of view, the average lead dust level across a large area in which the child plays and crawls is likely to better predict blood lead levels than the level at just one location.

Wipe and vacuum sampling methods may both be amenable to collecting composite samples. Composite wipe sampling requires a complete wipe to sample each location in the composite. Thus, if a composite sample comprises four subsamples, then four wipes must be used. The individual wipes making up each composite must then be placed in one container and analyzed by the laboratory as a single sample. If numerous wipes are analyzed as a single sample, however, a routine laboratory procedure may become nonroutine and require larger vessels, more analytical reagents, and more time to analyze. Jacobs (1993) conducted a

> *"pilot study to examine the feasibility of analyzing composite dust wipe samples...The samples were prepared by quantitatively transferring a known amount of NIST Urban Particulate (SRM #1648) to Little Ones® Baby Wash Cloths. The range of lead loadings selected was 200-1,000 µg/composite wipe. The wipes were packaged in 50 ml polyethylene centrifuge tubes with four wipes placed in each tube."*

From the pilot study results, Jacobs concluded that acceptable recoveries (within the range of 80 to 120%) could be achieved for composite wipe sampling and estimated the cost of analyzing a composite containing four wipes at about one-and-a-half times that for one single wipe. Thus, four single wipes that would cost $80 to analyze individually ($20 each) would cost only $30 to analyze if composited. Jacobs states that the increased cost is due primarily to the increased amount of acid required and the extra time for sample digestion.

Ashley (1993) does not support the practice of composite wipe sampling, however. He contends that analyzing composited premoistened disposable wipes may significantly increase the costs of analysis and suggests that laboratories may cut corners while analyzing composited wipe samples, thus leading to low recoveries.

Composite vacuum sampling is performed by vacuuming each location in the composite into one collection container. After all locations of the composite are vacuumed, the container is removed from the vacuum sampler and sent to the laboratory as one sample. At least one potential drawback exists with composite vacuum sampling. In very dusty households, too much dust may be vacuumed up from the locations that make up the composite, increasing the costs of laboratory analysis to accommodate the excess dust.

7.3 Exposure Assessments

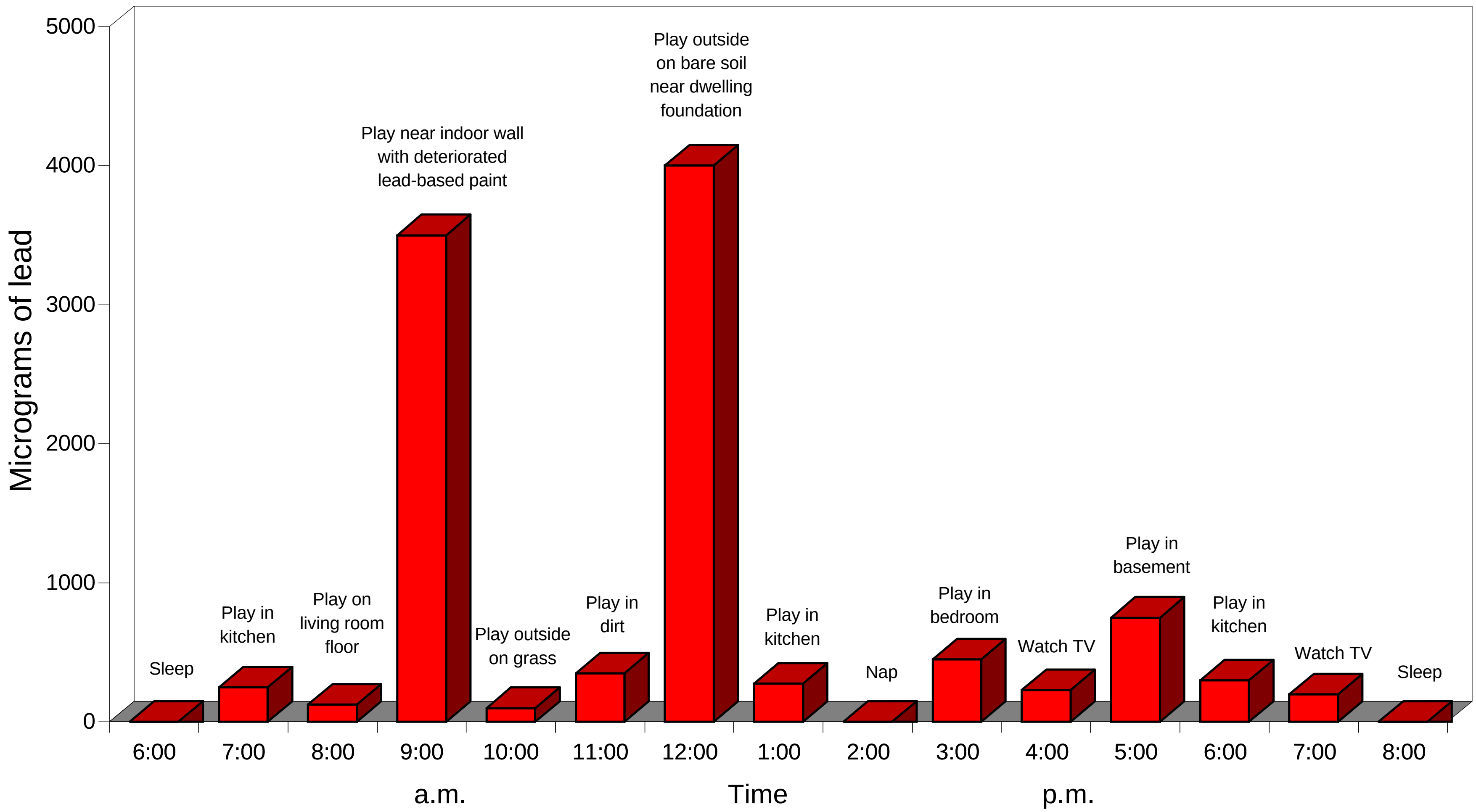
Although ingested house dust is widely considered a major cause of childhood lead poisoning in the United States, no one knows how to isolate and measure the lead dust a child picks up. While some information is available on the dust particle sizes on children's hands, little is known about whether children ingest only loose dust or ground-in dust or both. It is also unclear how much of the dust a child has contact with is actually ingested. To help answer these questions, an exposure assessment sampling strategy should be designed to collect dust which approximates this unknown fraction of house dust that reflects the true lead exposure to a child.

As an example of how a child may be exposed to lead in house dust, Figure 7-1 shows a simplified daytime lead exposure profile of a hypothetical child, reported in micrograms of total lead exposure from dust (y axis) versus time (x axis). For this child, lead exposure is dominated by two highly contaminated locations in the residence: play areas near an interior wall with deteriorated lead-based paint and bare soil near the dwelling foundation. The hypothetical case in Figure 7.1 may not be the most common exposure profile of a child, however. The child's exposure profile may look more like Figure 7.2. In this hypothetical example, the child is exposed to similar lead levels throughout the dwelling.

Biological lead levels are often monitored during exposure assessments. The amount of lead is usually measured in the blood and compared to guidelines for acceptable blood lead levels. As with the unknown variation in house lead dust measurements, the levels of lead in the human body change over time, and unknown error is associated with sampling and analyzing body tissue.

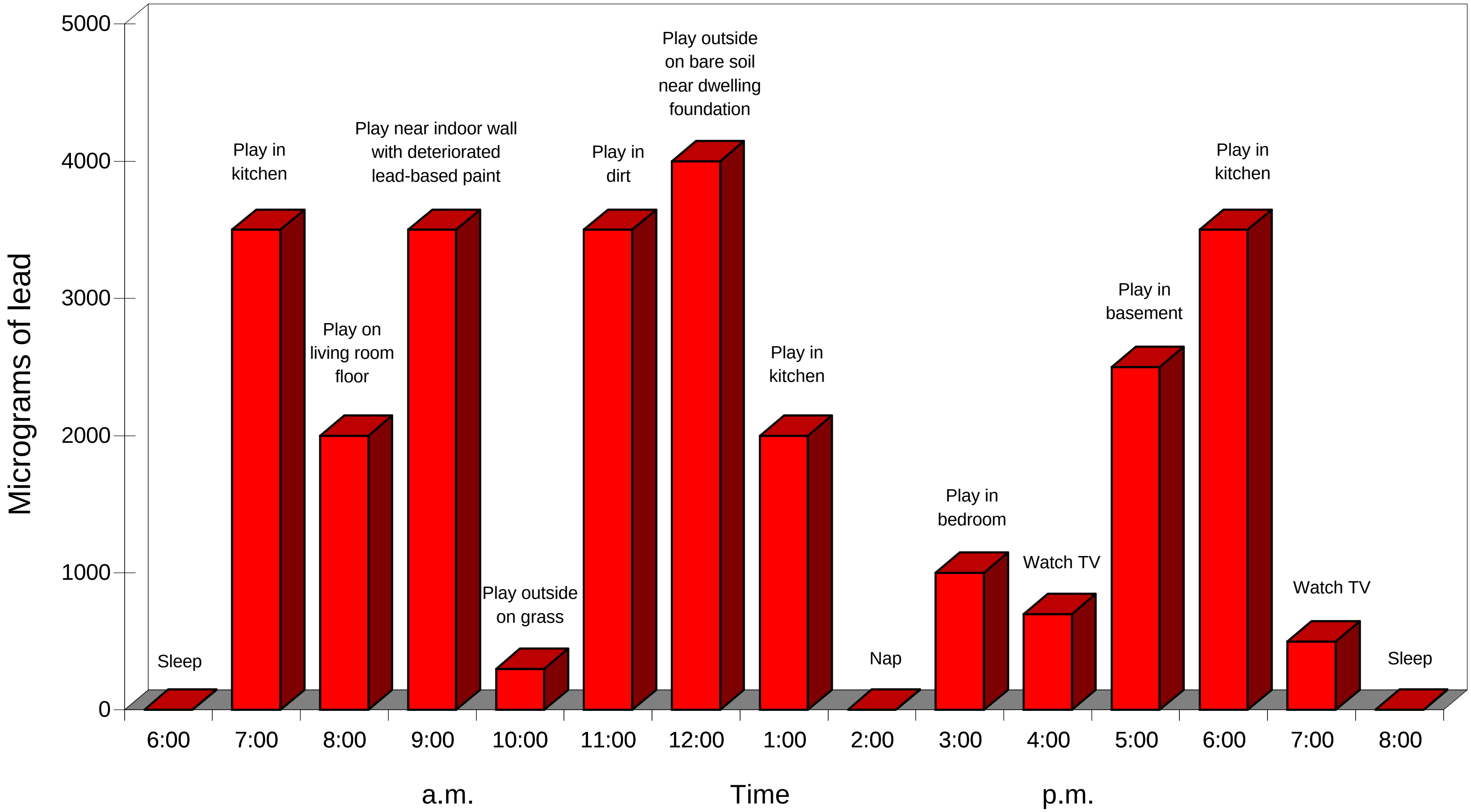
Assuming minimal fluctuation in the intake of lead, blood lead levels should remain relatively stable over long periods of time. Short-term changes in a child's environment before sampling, possibly influenced by sporadic house cleaning practices or by a child who just returned home from vacation, may offset dust/ blood lead relationships due to the timing of sample collection and to shifts in equilibria between lead in bone and other parts of the body. In some cases, the sole source of lead measured in the blood may be internal and may not reflect environmental lead levels at all. The sampling method and the laboratory analysis procedures may also influence estimates of the dust/ blood lead relationship.

Figure 7.1 Simplified Daytime Lead Exposure Profile of a Hypothetical Child (Example A)



Exposure profile concept from Ott, W.R.: Total Human Exposure. An emerging science focuses on humans as receptors of environmental pollution. Environ Sci Technol, Vol 19, No 10, 1985

Figure 7.2 Simplified Daytime Lead Exposure Profile of a Hypothetical Child (Example B)



Exposure profile concept from Ott, W.R.: Total Human Exposure. An emerging science focuses on humans as receptors of environmental pollution. Environ Sci Technol, Vol 19, No 10, 1985

Figure 7-3 outlines a simplified version of the lead pathways in a child's environment. The dust ingestion route is shown in bold lines. The figure also shows the sampling pathways to measure blood lead and house lead dust levels. As discussed throughout this report, many known and unknown factors influence the interpretation of house lead measurements. Interpretations of blood lead results present their own set of problems.

An exposure assessment sampling strategy can be designed to approximate the true lead exposure to a child by determining the lead levels in a medium (e.g., house dust) and a location (e.g., kitchen floor). This information can be linked with the amount of time that the child contacts the medium and location. The lead level and the time of contact may be characterized separately. The EPA calls this approach to estimating exposure a *scenario evaluation*.[4] The set of assumptions subsequently formulated about how lead contact occurs is an *exposure scenario*.

A child's contact with lead, such as when dust-laden fingers or objects are put in to the mouth, is called *exposure*. A child's lead exposure to dust is highly variable within time (from hour to hour) and space (from one side of the room to the other) because exposure depends on the sources of lead, the pathways, the total dust loading, and the amount of lead in the dust. The greatest variation in exposure, however, may be introduced by the child's activity. When dusty fingers or contaminated objects are put into the mouth, a portion of the dust is swallowed. Some of the lead in the swallowed material is then available for absorption into the gastrointestinal tract and, subsequently, for interaction with any organ or cell in the body. This portion of lead is called the *delivered dose*. Unfortunately, because there is no feasible way to directly measure what the child consumes, neither the true exposure concentration nor the delivered dose are generally known for house dust. The best estimate of

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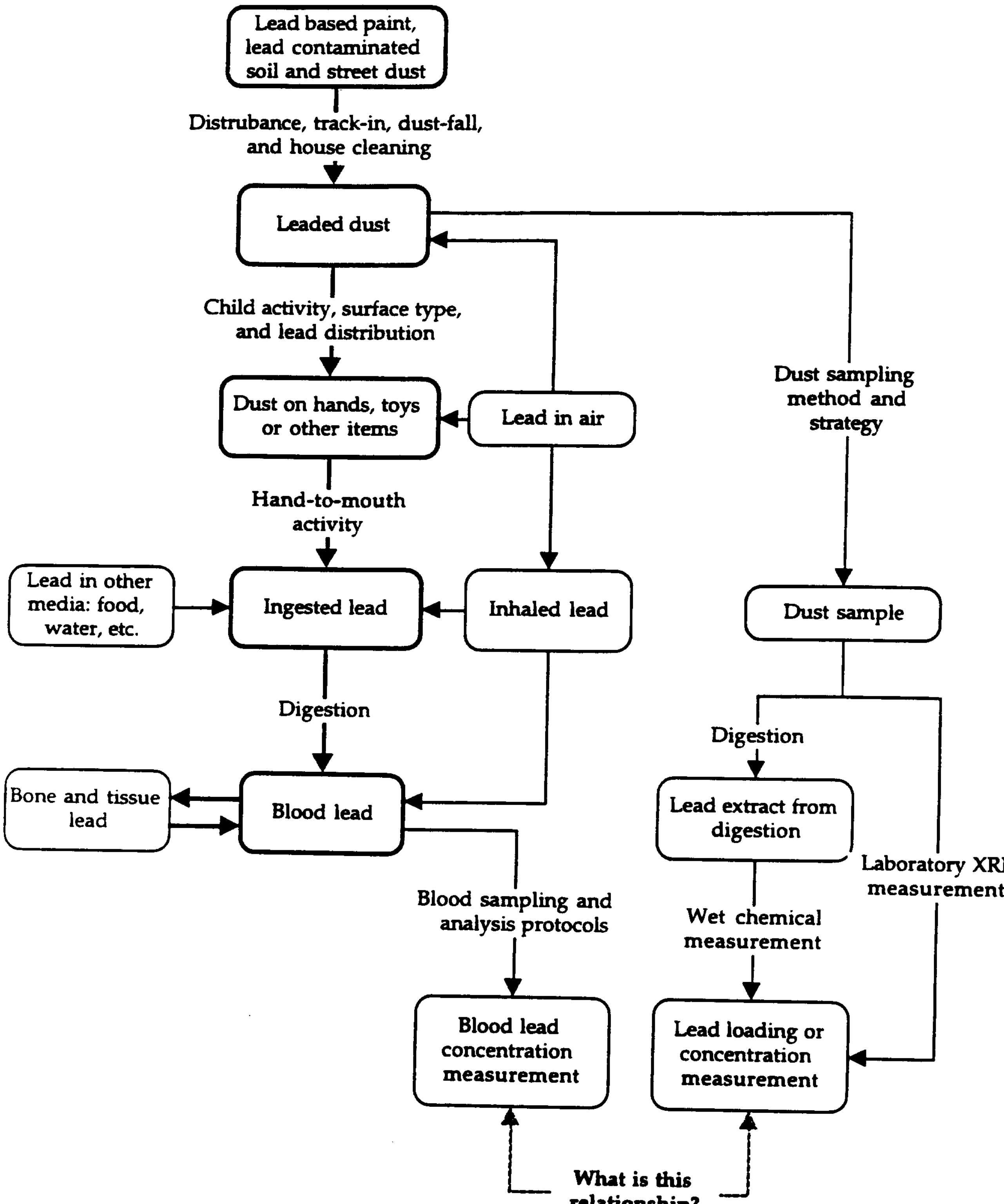
[4] U. S. Environmental Protection Agency. *Guidelines for Exposure Assessment*. Federal Register, Vol. 57, No. 104, Friday, May 29, 1992.

Figure 7-3 Simplified lead pathways and relationship to house dust sampling



true lead dust exposure comes from estimates of the average exposures collected in a child's daily physical environment. To increase accuracy of the estimates, these average lead levels can be weighted toward the amount of time the child spends in each area of that environment.

Possibly the best measures of house lead dust in relationship to children's blood lead levels are time-weighted averages of longitudinal dust lead measurements. However, no studies have been designed specifically to examine this issue. If one were to repeat sampling over time, averages across space and time could be obtained. However, most sampling strategies used in previous studies collected dust at only one point in time. An obvious advantage to cross-sectional (one time) studies is that they are less expensive than longitudinal (more than one time) studies, which require repeated visits to a dwelling and extensive laboratory analysis.

One possible approach to strengthening estimates of time-weighted average lead dust levels in cross-sectional studies may be to measure exposure-weighted average lead levels based on the activity of the child. This can be done by listing indoor locations where the child spends time, then roughly estimating the percent of time spent actively in each location, rounded to a convenient percentage. Samples can then be composited from the specific areas by adjusting the subsample areas to be proportional to the percent of time spent in each area. An exposure-weighted average lead dust level can then be estimated from the result. For example, for a young child, a typical pattern might be 40 percent time spent in the family room, 40 percent in the child's bedroom, and 20 percent in the kitchen. In this case, **two** one-square foot subsamples can be taken from accessible areas in the family room and **two** one-square foot subsamples from the bedroom because 40 percent of the child's time is spent in each of these rooms. **One** one-square foot can be subsampled on the kitchen floor because 20 percent of the child's time is spent there. Thus, the composite sample, comprised of the five subsamples listed above, can be roughly exposure-weighted to the specific areas frequented by the child since five subsamples (20% each) correspond to one composite sample (100%). It should be noted that no scientific study to date has been designed to test the efficacy of applying the sampling strategy discussed here for determining a child's health risk to lead dust.

7.4 Primary Prevention Lead Risk Assessments

The main objective of primary prevention lead risk assessments is to identify the magnitude and location of lead-based paint hazards in a dwelling so the hazards can be controlled. These assessments are designed to *prevent* children from being lead poisoned. Ideally, this type of assessment is done in conjunction with a careful visual examination of the property by a trained professional, by collecting dust and soil lead samples, and by measuring lead levels in deteriorated paint samples. Recommendations are then given to property owners or other interested parties on the best ways to control identified lead-based paint hazards. Another important objective is to perform the assessment at an affordable price to enable most home owners of pre-1978 housing to have such an assessment conducted.

House dust sampling is an integral part of a risk assessment. As noted previously, however, house dust levels may vary according to where the sample is taken. They also may vary greatly over time. For example, dust levels may change from before-to-after house cleaning, such as from vacuuming, sweeping, or mopping. The variation of dust levels across the floor or other surface, the sources and amounts of lead contamination, and the accessibility to humans may also vary greatly from person to person, from room to room, and from house to house. Due to this large variability, the person responsible for sampling house dust during a risk assessment is challenged to make meaningful sampling location decisions and to draw useful conclusions from the results.

Sampling locations may be chosen based on information obtained during a preliminary visual assessment to locate potential lead-based paint hazards. The choice may also depend on the professional judgment of the risk assessor. If analytical costs were trivial, then a dozen or more house dust samples could be collected in each dwelling unit to characterize lead hazards. But analytical costs, in the range of $20 per sample, are not trivial. Therefore, to keep costs affordable, sampling strategies must limit the number of house dust samples collected. Unfortunately, limiting the number of samples increases the need for good professional judgment and, in turn, may increase the uncertainty in the sample results. Inaccurate or incomplete conclusions about house lead dust levels may be harmful to a child if an existing hazard is not identified. Inaccurate conclusions may also be unnecessarily expensive to an owner instructed to correct hazards that do not exist.

Information about lead concentration levels, in addition to information about lead loading, may be useful for assessing and remediating housing associated lead hazards. The accumulation of dust and lead in a dwelling depends on the rate of dust generation by particular sources, the lead concentration in the dust being generated, and the tendency for surfaces to trap leaded dust particles. Since vacuuming and mopping house dust cannot reduce lead concentration, unless lead particles are preferentially removed over nonlead particles, the concentration in the dust before cleaning should be similar, on average, to the concentration of the dust that re-accumulates after cleaning. This conclusion is based on the assumption that lead concentration remains fairly constant as lead loading increases. Since the accumulation rate of dust is not known and likely to be highly variable from house to house, and the timing of sampling in relation to cleaning is usually not known, it may be rational to promote more aggressive lead hazard control measures and education in dwellings that have high dust lead concentration levels. Controlling surface dust lead levels in these dwellings may be more difficult than in dwellings with low dust lead concentrations. However, the presupposition that dust lead concentration provides additional important information for primary prevention risk assessment is untested.

8. CRITERIA FOR SELECTING APPROPRIATE SAMPLING METHODS

As noted throughout this report, there are many factors that affect house dust sampling results. These factors include the physical variability of lead concentration and total dust per unit area, the collection efficiency of the sampling method, the surfaces sampled, the timing of sample collection, and the analytical method used to measure lead levels. In this section, numerous criteria are discussed that may be relevant to selecting an appropriate sampling method for a specific situation. The researcher or regulator must decide which sampling technology is appropriate for his or her needs. Currently, practitioners can obtain guidance from EPA and HUD on dust sampling protocols (U.S. EPA, July 1994; U.S. HUD, 1995).

Table 8-1 shows selected sampling methods described in this report and qualitatively rates them according to a set of important criteria. The methods selected were chosen based on current information on their utility. For example, the preweighed wipe methods, with the exception of the LWW method, are not included in the table because they are not practical for widespread use and may be difficult for a laboratory to handle. The OSHA wipe sampling method was not included because it provides only qualitative information, and the filter paper used to wipe surfaces sometimes falls apart. However, methods not included on the table may also be appropriate for specific research needs.

Table 8-1: Sampling Methods by Selected Criteria

	Selected Criteria									
Selected Sampling Methods	Widely available	Simple sampling procedures	Measures lead loading	Measures lead concentration	Laboratory sieving possible	Light weight and portable	Samples in small areas (e.g., window sills)	AC powered	Blood Lead Relationship Studied	Cost
Total Lead Wipe (HUD method)	Y	Y	Y	N	N	Y	Y	N	Y	$
LWW Wipe	N	N	Y	Y	N	Y	Y	N		$
DVM	Y	Y	Y	Y	N	Y	Y	N	Y	$
BRM-HVS3	N	Y	Y	Y	Y	Y	Y	Y	Y	$
HVS3-ASTM D5438-93	N	N	Y	Y	Y	N	N	Y		$
CAPS Cyclone	N	Y	Y	Y	N	Y	Y	Y	N	$
Sirchee-Spittler	N	Y	Y	Y	Y	Y	Y	N	Y	$
Blue Nozzle	N	Y	Y	Y	N	Y	Y	Y	N	$

Legend		
Y = Yes	$	= Least expensive
N = No	$	= Moderate
Blank = Information not available	$	= Most expensive

Completing Table 8-1, as well as choosing an optimal sampling method, is difficult, as noted earlier, because techniques to characterize sampling methods are not standardized. It is not known, for instance, if characterizing a sampler in a laboratory is meaningful. It is also not known if endpoints of characterization studies, such as sampler collection efficiencies for different surfaces and different particle sizes, have reasonable relationships to children's lead dust exposure. Determining the relative collection efficiencies from surfaces by particle size may be important in comparing one sampling device with another, and so, with the current limited state of knowledge, samplers cannot be judged solely on percent recovery.

The best sampler characterization studies are most likely completed in the field and include children's blood lead measurements. However, the Lanphear (1995) field study is the only large study that compared blood lead information with different house dust sampling methods side by side. Furthermore, it is not known if the choice of sampling locations and the timing of the sampling is more important than which sampler is used in a particular study. How, for example, would changing the Lanphear study's sampling strategy have affected the results and conclusions?

As noted earlier, the needs of a practical regulatory method and the specialized needs for research methods may be different. The regulatory method must be capable of being used by a large number of individuals in a variety of settings. It should be inexpensive and require a minimum number of procedures. Research samplers used on a limited scale are usually expensive and may require lengthy procedures for decontamination between samples. If local governments, housing and public health offices, and contracting companies are required to collect large numbers of routine samples nationwide, then high sampler cost and sampling time requirements may be a great burden on their budgets. In general, the common wipe methods are less expensive and easier to use than the vacuum methods. On the other hand, if a vacuum method were adopted, economies of scale in production might reduce the unit cost of samplers considerably. Finally, if lead concentration measurements are needed, then common wipe methods cannot be used.

9. CURRENT LEAD DUST RESEARCH

In this section, a dozen studies are briefly described that provide information in lead dust research. Table 9-1, a matrix at the end of this section, shows each of these studies by the particular sampling method used.

9.1 Baltimore Lead-Based Paint Abatement and Repair and Maintenance (R&M) Pilot Study

The EPA R&M pilot study was conducted in six Baltimore dwellings (Battelle, 1992) and sampled settled dust on floors, windowsills, window wells, and upholstered furniture using the Blue Nozzle sampler. Dust was collected at a sampling rate of 2 minutes per square foot in overlapping passes (left to right, front to back). A modified University of Cincinnati method for preparation and digestion of vacuum dust samples was used (i.e., rinse dust from plastic filter cassettes into preweighed 50 milliliter beakers; conduct a "total" microwave digestion). Eighteen percent of the routine vacuum samples contained less than 10 milligrams of dust, and 28 percent of these were eliminated from analysis because they contained less than 2 milligrams of dust. Two milligrams of dust was determined as the minimum weight change discernible in the preweighed beaker.

Findings showed that window wells had the highest dust loadings, lead loadings, and lead concentrations. The study also found that within-room variability was the largest source of variability. Results suggested that further research to investigate side-by-side dust sampling will allow a direct comparison between location and within-room variability. The R&M pilot study suggests that side-by-side dust sampling is important in determining within-room variability.

The R&M pilot study included two substudies. One called for side-by-side wipe and vacuum dust samples. This study collected wipe samples on a commercially-available brand of wipes and extracted the lead with 0.1 N HCL. The substudy concluded that side-by-side wipe and vacuum floor dust samples were highly correlated ($r=0.84$; $p < 0.001$; $n=68$). However, findings also revealed wipe lead loadings that were 3.4 to 5.6 times higher than those observed in vacuum samples.

The data from the second substudy showed a high correlation ($r=.945$; $p < 0.001$) between floor lead loadings determined by composite samples and weighted averages of multiple floor samples. Regression analysis and modeling of composites and weighted averages suggest that compositing dust from several locations furnishes a cost-effective and viable method of screening for lead in dust.

9.2 Baltimore Lead-Based Paint Abatement and Repair and Maintenance Study (R&M Study)

This ongoing EPA study is a followup to the R&M pilot study and compares comprehensive lead-paint abatement with low-cost repair and maintenance for their efficacy in reducing lead dust levels in housing and children's blood lead levels. The BRM-HVS3 sampler is being used in this study with a composite sampling strategy (Farfel, 1993). "BRM" is derived from "Baltimore Repair and Maintenance." Since this study is not finished, there are no results to report.

9.3 Comprehensive Abatement Performance Pilot Study (CAP Pilot Study)

The EPA CAP pilot study was designed in part to assess the performance of sampling and analysis methods and to compare the vacuum/ total digestion protocol planned for the full CAPS study with the wipe protocol previously used in the HUD demonstration project and other studies (U.S. EPA, February 1995). This is a total digestion of the wipe sample and should give higher lead results than the lead-leaching method used in the R&M pilot study. Within each room selected for comparative sampling, two side-by-side floor samples were collected using both the vacuum and wipe sampling methods. Wipe sampling was accomplished with the same brand and procedures used in the HUD demonstration project. As in the R&M pilot, vacuum sampling was accomplished by the Blue Nozzle method. The wipe sampling procedures showed lead loadings ($\mu g/ft^2$) for floor samples to be approximately 5 times higher, and lead loadings for window well samples to be approximately 5 times higher, than samples collected by the Blue Nozzle method.

9.4 Comprehensive Abatement Performance Study (CAP Study)

In the EPA CAP study, side-by-side wipe/vacuum samples were collected in 34 abated homes (Battelle, 1995). While the Blue Nozzle sampler was used in the pilot study, the CAP cyclone vacuum sampler was used in the full study. In this study, the two sampling methods were not statistically different over all substrates tested. The estimate of vacuum/wipe ratio was 1.38, with a confidence interval of 0.75 to 2.54. But the bias between the two methods appeared to increase with the roughness of the substrate. It was also found that, on average, side-by-side vacuum measures were significantly more variable than wipe measures.

9.5 MRI Engineering Study to Explore Improvements in Vacuum Dust Collection

The EPA-sponsored MRI Engineering Study was designed to investigate the possibility of developing an improved dust collector based on comparisons among the Blue

Nozzle sampler, another in-line sampler (a modified Blue Nozzle sampler with a smaller diameter inlet and two pumps pulling air in parallel), and the CAPS cyclone sampler (Lim et al., 1995). To test the samplers, artificial dust was prepared in the laboratory with three different particle size ranges: less than 250 µm, 250 µm to 2,000 µm, and all particles less than 2,000 µm. The artificial dust consisted of dirt, sand, and paint chips and was applied to a surface by hand as evenly as possible over the one foot square inscribed area of the surface. Each sampling test consisted of vacuuming a one-square foot area on wood floor, linoleum, concrete, carpet, or a windowsill. Dust was not ground into the carpets. A minimum dust collection efficiency criterion was set at 85 percent.

The CAP study cyclone sampler exhibited the highest efficiency of the three sampling methods used in the study. The mean collection for all but one surface exceeded 90.4 percent. The exception was the carpeted surface with small particle size dust (< 250 µm). It is possible that some of the smaller particles did not settle in the sampler and were discharged into the room along with the vacuum exhaust air. Alternatively, static electricity can cause fine particulate matter to adhere to the carpet fibers, the inner surfaces of the sampler, the nozzle, and the connecting tube and would prevent these particles from being measured.

The Blue Nozzle dust collector was most efficient on concrete, linoleum, and wood floors (44 to 59%). A low mean collection efficiency for the windowsill (near 0%) was observed because the Blue Nozzle inlet was too wide to fit flatly into the window sill channel.

The modified Blue Nozzle in-line dust collector was more efficient than the standard Blue Nozzle sampler on all surfaces. Collection efficiencies ranged from 88 to 98 percent on all surfaces except on carpets, where efficiency was 50 to 65 percent.

The authors' interpretation of the results showed the Blue Nozzle sampler to be the least efficient for dust sampling. The in-line dust collector was more efficient but fell short of the 85 percent efficiency rate set for this study. Except for the smallest size particles on the carpeted surfaces, the CAPS cyclone sampler achieved greater than 85 percent efficiency.

9.6 EPA Childhood Lead Exposure and Reduction (CLEAR) Study

This EPA study is examining lead hazards in low-income housing in New Jersey. The aims of the study are to: (1) quantitate lead content in paint, in water, and in household dust of children's homes, as well as in nearby soil; (2) estimate each child's exposure derived from contact with lead from different media and routes of exposure; (3) identify biological and other markers measurable, prenatally and in the first 9 months of life, that can best predict blood lead at age 2; and (4) test a vigorous intervention-exposure reduction program in a randomized trial to examine its capacity to minimize the increase on blood lead that usually occurs in younger inner city children. The approach will combine a lead reduction educational program with biweekly help in dust control. The LWW wipe sampling method and the Lioy vacuum method are being used to collect house dust for this study. Sampling protocols or results from this study are not currently available.

9.7 CDC/NCEH and NIOSH FBI Take-Home Lead Study

This study was designed in part to assess the risks of para-occupational lead exposure (take-home lead) among children of gunsmiths, technicians, and firearms instructors at the FBI Academy Firing Range in Quantico, Virginia (NIOSH, 1994). The staff studied are occupationally exposed to lead. The DVM method was selected to collect dust in both exposed and non-exposed homes. Composite house dust samples were collected in automobiles, in entryways into the house, near dirty laundry areas, and in areas where children might play. Limited dust samples were also collected with the Sirchee-Spittler method, side-by-side with selected DVM samples. Blood lead levels were also measured in children and adults. Results from this study are pending.

9.8 NCLSH Comparison Study

The National Center for Lead Safe Housing, through the Fannie Mae Foundation, funded a pilot study to field test five different sampling methods, side by side (Jacobs, 1993). The study was conducted by the University of Cincinnati, and its primary purpose was to identify sampling techniques to be used in the Lanphear (1995) Study. The sampling methods included the University of Cincinnati DVM method, the BRM-HVS3 sampler, the HUD wipe method, Farfel's wipe method, and the LWW wipe sampling method. Researchers from the University of Cincinnati collected five side-by-side samples in 20 homes, in three rooms per home, and two samples per room. One sample by each method was also collected on concrete outside of each home. Based on the results of the pilot, the DVM, BRM, and the HUD wipe sampling methods were used in the Lanphear Study.

9.9 Lanphear Study

The purpose of this study, awarded to a research group in Rochester, New York, was to assess the relationships between settled lead dust and blood lead levels in children, using three methods chosen from the NCLSH pilot study (Lanphear, 1995). Study objectives, as specified by the request for proposal, included quantifying the relationships among a wide range of settled dust levels and blood lead levels. Methods included using side-by-side vacuum and wipe sampling on floors, windowsills, and window wells in at least three rooms per dwelling unit, including the child's bedroom and the principal play area. Lead samples in other media were also collected including, but not limited to, paint, water, and soil.

A sample of at least 200 children, from a high lead-risk population of low socioeconomic status, was selected as participants for the study. Three different dust sampling methods, the DVM, the BRM, and the HUD wipe method were used to collect lead dust on various surfaces. The study attempted to obtain lead dust levels in terms of both lead loading and lead concentration (except for the wipe samples). The principal aim was to provide a sound foundation for the adoption of a health-based lead standard that would define dangerous levels of lead in house dust, using a single sampling and analytical method. Examining the independent contribution to blood lead levels from dust lead on floors, windowsills, and window wells was of particular importance.

9.10 NIOSH Take-Home Study

This NIOSH study, being conducted in collaboration with the New Jersey Department of Health, is designed to characterize the extent of take-home lead exposure in children of construction workers and the effect of such exposure on the blood lead levels of these children compared to neighborhood controls (Whelan, 1994). The primary objective of the study is to evaluate the extent of lead taken home from the workplace by New Jersey construction workers. A quantitative assessment of lead contamination in each home was made with the DVM vacuum method and the HUD wipe sampling method. The primary hypothesis to be tested is whether children of construction workers have significantly higher blood lead levels than neighborhood children of the same age whose parents are not employed in a lead-related industry. A secondary hypothesis concerns to what degree workplace hygiene practices (e.g., use of showers, changing facilities) influence the extent of lead taken home from the work site. Results from this study are forthcoming.

9.11 EPA/OPPT Laboratory Evaluation Study

This project was undertaken by the EPA/ OPPT to evaluate house dust sampling methods and to assess the efficacy of typical household vacuuming on removing lead dust from residential surfaces (U.S. EPA, in press). The sampling methods tested include the BRM-HVS3, the CAP study Cyclone, the Blue Nozzle method, and the HUD wipe method. Lead dust sampling results from the National Survey of Lead-Based Paint in Housing were also reexamined, based on new information collected in the study about the performance of the Blue Nozzle method, which was used during the national survey of lead-based paint (U.S. HUD, 1990).

The results from the study indicate that the BRM and CAP study cyclone produced the highest recoveries across all substrates and particle size classes. The samplers, in order of decreasing lead recoveries across all substrates and particle sizes, were the BRM, the CAP study cyclone, the HUD wipe method, and the Blue Nozzle method. The lead recovery of the Blue Nozzle sampler was significantly lower than for the other samplers tested.

9.12 EPA Nine-Home Lead Study

This study was conducted in 1991 to evaluate sampling methods that can be used to estimate children's exposure to lead in the home. House dust samples were collected in nine homes with the original HVS3 sampler. Dislodgeable dust was also collected with a hand-press sampling technique and with a roller-sampler. The final report from this study has not yet been released.

Table 9-1. Summary of Current Research and Dust Sampling Methods Used

Sampling Method	Study											
	BRM Pilot	BRM	CAP Pilot	CAP	MRI Eng	CLEAR	CDC	NCLSH	Lan-phear	NIOSH	EPA/ OPPT	EPA9 Home
Blue Nozzle	√		√		√						√	
Bioavailable wipe (Farfel)	√							√				
Total wipe (HUD)			√	√				√	√	√	√	
CAPS cyclone				√	√						√	
MRI in-line dust collector					√							
LWW wipe						√		√				
Lioy's vacuum						√						
DVM							√	√	√	√		
BRM-HVS3		√						√	√		√	
HVS3-ASTM D5438-93												√
Dislodgeable methods												√

10. CONCLUSIONS AND RECOMMENDATIONS

This report has presented critical concepts about house lead dust sampling, reviewed current literature and research, and compared numerous sampling techniques and procedures. The following unresolved points reiterate main themes throughout the report:

- Dust sampling methods vary substantially in performance both between methods and within methods on different surface types.
- There is no standardized way to compare and characterize dust samplers.
- It is not clear what the best sampling strategies are to predict children's lead exposure.
- There are currently no health-based standards for house dust.
- No scientific studies have compared the merits of measuring lead dust concentration in addition to lead loading during primary prevention lead risk assessment.
- The spatial and temporal variability of dust lead loading and lead concentration are not well known.

As shown throughout this report, much research has been done and much still remains to be done. One important area for research is the development of a standardized method to characterize house dust samplers to establish a baseline for the future. Ideally these characterization studies should be conducted in the field with corresponding information on children's blood lead levels. Further work is also needed to assess the usefulness of laboratory characterization studies. After these analyses are complete, it may be possible to compare different sampling methods and make meaningful interpretations of the inherent differences in results from one method to another. Health-based household dust lead standards, when they are developed, may need to be adjusted for a particular sampler because relative differences may affect relationships with blood lead levels. The ability to adjust sampling results based on their actual relationship to children's blood lead levels is necessary because many of the different sampling methods described in this report will continue to be used for the foreseeable future.

Other recommendations include conducting further research to examine the dust/blood lead relationship. Numerous studies have documented this relationship but usually with only one sampling method and one sampling strategy. Future studies are needed with objectives similar to those of the Lanphear (1995) study, which assessed different sampling methods side by side, and compared their results to children's blood lead levels. However, only one sampling strategy was used, even in the Lanphear study.

Because data are limited or questionable, further research is needed on the characteristics of dust that sticks to children's hands and that which is ingested. New, powerful, analytical research tools are available today that may permit a close look at the properties of this dust. Dust adherence on children's hands should be re-examined to see if new findings with more sophisticated equipment agree with previous findings.

Practitioners should refer to the HUD Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing (U.S. HUD, June 1995) for guidance on how to collect settled dust samples. The Guidelines were released in August 1995 and are available by calling HUD USER at 1-800-245-2691. The EPA has released Residential Sampling for Lead: Protocols for Dust and Soil Sampling (EPA 747-R-95-001) which can be obtained by calling the National Lead Information Center Clearinghouse at 1-800-424-LEAD. This document provides guidance for the collection of settled dust samples. Finally, the American Society for Testing and Materials (ASTM) has established a subcommittee on Abatement of Lead Hazards in Buildings. As part of this subcommittee, consensus standards have been and are being developed for a variety issues related to sampling house dust for lead.

11. BIBLIOGRAPHY

Adgate, John (1995, February 1). [personal conversation], Environmental and Occupational Health Sciences Institute, University of New Jersey School of Dentistry and Medicine, Piscataway, NJ.

American Society of Testing and Materials (ASTM) (1987). Evaluation of carpet-embedded dirt removal effectiveness of household vacuum cleaners (F608-79). *Annual Book of ASTM Standards*, Vol. 15., 07. American Society of Testing and Materials, Philadelphia, PA.

American Society Testing and Materials (ASTM) (1993). Method D 5438-93. Standard practice for collection of dust from carpeted floors for chemical analysis. ASTM, 1916 Race St., Philadelphia., PA 19103; (215) 977-9679.

Ashley, K. (1993, August). "Composite dust sampling with pre-moistened disposable wipes." [private conversation], National Institute for Occupational Safety and Health.

Ashley, K. (1994, February). "Digestion methods for lead analysis." [private conversation], National Institute for Occupational Safety and Health.

Ashley, K. and McKnight, M.E. (1994). Lead abatement in buildings and related structures: ASTM standards for identification and mitigation of lead hazards. ASTM E06.23 activities published in *ASTM Standardization News*.

Barltrop, D. and Meek, F. (1979, July/ August). Effect of particle size on the lead absorption. *Gutmann Archives of Environmental Health*, 280-285.

Barratt, R.S. (1990). An assessment of dust analysis: with particular reference to lead and certain other metals. *International Journal of Environmental Analytical Chemistry*, 40, 77-97.

Battelle Report to the EPA/ OPPT (1992, July 9). "Lead-based paint abatement and repair and maintenance pilot study."

Battelle Report to the EPA/ OPPT. (1992) "Comprehensive abatement performance pilot study: Volume I -- Results of lead data analysis."

Battelle Report to the EPA/ OPPT (1995). "Comprehensive abatement performance study. Volume II: Detailed Statistical Results."

Blume, K. (1993, July 2). Review of the first draft of this report.

Borschein, R.L., et al. (1985). The influence of social and environmental factors on dust lead, hand lead, and blood lead levels in young children. *Environmental Research*, 38, 108-118.

Bornschein, R.L., et al. (1986). Exterior surface dust lead, interior house dust lead and childhood lead exposure in an urban environment. *Trace Substances in Environmental Health*, 322-332.

Breen, J.J. and Stroup, C.R. (1995). Lead poisoning: exposure, abatement, and regulation. CRC Press, Inc.

Budd, W.T., Roberts, J.W., and Ruby, M.G. (1990). Field evaluation of a high volume surface sampler for pesticides in floor dust. EPA 600/ 3-90/ 030.

Butte-Silver Bow Department of Health and University of Cincinnati Department of Environmental Health. (1991, June 10). "The Butte-Silver Bow environmental health lead study." Draft Final Report.

Camann, D.E. and Lewis, R.G. (1990, July 29 to August 3). Trapping of particle-associated pesticides in indoor air by polyurethane foam and exploration of soil track-in as a pesticide source. Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto.

Centers for Disease Control. (1991). Strategic plan for the elimination of childhood lead poisoning. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control.

Charney, E., Kessler, B., Farfel, M., and Jackson, D. (1983). Childhood lead poisoning: A controlled trial of the effect of dust-control measures on blood lead levels. *New England Journal of Medicine*, 309 (18), 1089-1093.

Chavalitnitikul, C. and Levin, L. (1984). A laboratory evaluation of wipe testing based on lead oxide surface contamination. *American Industrial Hygiene Association Journal*, 45 (5), 311-317.

Clark, S., et al. (1991). Urban lead exposures of children in Cincinnati, Ohio. *Chemical Speciation and Bioavailability*, 3(3/ 4), 163-171.

Davidson, C.L. and R.W. Elias (1986). Environmental concentrations and potential pathways to human exposure. U.S. Environmental Protection Agency: Research Triangle Park, NC, Air Quality Criteria for Lead, Chapter 7.

Davies, D.J.A., Thornton, I., Watt, J.M., Culbard, E.B., Harvey, P.G., Delves, H.T., Sherlock, J.C., Smart, G.A., Thomas, J.F.A., and Quinn, M.J. (1990). Lead intake and blood lead in two-year-old U.K. urban children. *The Science of the Total Environment*, 90, 13-29.

Derosa, C.T., Choudhury, H., and Peirano, W.B. (1991). An integrated exposure/ pharmacokinetic based approach to the assessment of complex exposures. Lead: A Case Study. *Toxicology and Industrial Health*, 7 (4), 231-248.

Diemel, J.A.L., Brunekreef, B., Boleij, J.S.M., Biersteker, K., and Veenstra, S.J. (1981). The Arnhem lead study. II. Indoor Pollution, and Indoor/ Outdoor Relationships. *Environmental Research*, 25, 449-456.

Driver, J.H., Konz, J.J., and Whitmyre, G.K. (1989). Soil adherence to human skin. *Bulletin of Environmental Contaminants and Toxicology*, 43, 814-820.

Duggan, M.J., Inskip, M.J., Rundle, S.A., and Moorcroft, J.S. (1985). Lead in playground dust and on the hands of school children. *The Science of the Total Environment*, 44, 65-79.

Duggan, M.J. and Inskip, M.J. (1985). Childhood exposure to lead in surface dust. *Public Health Review*, 13, 2-54.

Elias, R.W. (1994, January 10-11). "Collection of lead-containing dust using walk-off mats," presented at the National Human Exposure Assessment Survey (NHEXAS) Workshop to Identify Optimal Dermal Exposure Sampling Methodologies. Atmospheric Research and Exposure Assessment Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Eller, P.M., Ed. (1984). *NIOSH Manual of Analytical Methods,* 3th ed., Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Publication Number 84-100.

Eller, P.M., Ed. (in Press). *NIOSH Manual of Analytical Methods,* 4th ed., Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Method #0700.

Ewers, L. (1993, April 20). "House Dust Characteristics" [personal conversation]. Dr. Linda Ewers, National Institute for Occupational Safety and Health.

Farfel, M.R. and Chisolm, J.J. (1990). Health and Environmental outcomes of traditional and modified practices for abatement of residential lead-based paint. *American Journal of Public Health,* 80 (10), 1240-1245.

Farfel, M.R. and Chisolm, J.J. (1991). An evaluation of experimental practices for abatement of residential lead-based paint: Report on a pilot project. *Environmental Research*, 55, 199-212.

Farfel, M.R. (1993, March 23). "Origin of the MD dust-lead clearance numbers." [personal conversation]. Dr. Mark Farfel, Department of Health Policy and Management, Kennedy Krieger Institute, Baltimore, MD.

Farfel, M.R. (1993, March 23). "Modified HVS3 sampler vs. MRI particle separation chamber." [personal conversation]. Dr. Mark Farfel, Department of Health Policy and Management, Kennedy Krieger Institute.

Farfel, M.R. (1993, July 25-29). "The lead paint abatement and repair and maintenance study in Baltimore." Presented at the American Society Testing and Materials (ASTM) Boulder Conference on Lead in Paint, Soil, and Dust.

Farfel, M.R., et al. (1994). Comparison of two cyclone-based collection devices for the evaluation of lead-containing residential dusts. *Applied Occupational and Environmental Hygiene Journal*, 9(3), 212-217.

Farfel, M.R. and Rohde, C.A. (1995). Determination of Environmental Lead, Using Compositing of House Dust Samples. Chapter 26 in Breen, J.J. and Stroup, C.R. (1995). Lead poisoning: exposure, abatement, and regulation. CRC Press, Inc.

Fergusson, J.E. and Kim, N.D. (1991). Trace elements in street and house dusts: Sources and speciation. *The Science of the Total Environment*, 100, 125-150.

Fortman, R.C., et al. (1991). Final report of the house dust/ infant pesticides exposure study (HIPES). Methods Research Branch, Atmospheric and Exposure Assessment Laboratory, Office of Research and Development, U.S. Environmental Protection Agency.

Fortman, R.C., Sheldon, L.S., Camann, D.E., and Lewis, R.G. (1991, May). Field measurement methods to assess exposure of children to pesticides in the home. Presented at the EPA/ A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC.

Hirsh, J. (1993, March 24). "Modified HVS3 sampler." [personal conversation]. Jack Hirsh, President, CS3, Inc.

Hoppin, J. (1993, April 21). "Kinetics of Lead in Children." [personal conversation]. Jane Hoppin, Ph.D. Student, Harvard School of Public Health.

Jacobs, D.E., Menreath, W.B., Succop, P.A., Cohen, R., Clark, S.C., and Bornschein, R.L. (1993, June 15). A comparison of five sampling methods for settled lead dust: A pilot study. Preliminary Draft Report.

Jacobs. D.E. ("1993, November 17). Feasibility of analyzing composite wipe samples for lead." Memo by Dave Jacobs, Deputy Director, National Center for Lead Safe Housing. Available from the National Center for Lead-Safe Housing, 10227 Wincopin Circle, Suite 205, Columbia, MD 21044.

Jensen, H. (1992). Lead in Household Dust. *The Science of the Total Environment*, 114, 1-6.

Kaye, W.E., Novotny, T.E., and Tucker, M. (1987). New ceramics-related industry implicated in elevated blood lead levels in children. *Archives of Environmental Health*, 42 (2), 161-164.

Lanphear, B., et al. (June, 1995). The relationship of lead-contaminated house dust and blood lead levels among urban children. Final Report by the Department of Pediatrics, Biostatistics, and Environmental Medicine, The University of Rochester School of Medicine, Rochester, New York, and The National Center for Lead-Safe Housing. U.S. Department of Housing and Urban Development Grant # MLDP T0001-93.

Laxen, D.P.H., Raab, G.M., and Fulton, M. (1987). Children's blood lead and exposure to lead in household dust and Water -- A basis for an environmental standard for lead in dust. *The Science of the Total Environment*, 66, 235-244.

Lepow, M.L., Bruckman, L., Rubino, R.A., Markowitz, S., Gillette, M., and Kapish, J. (1974). Role of airborne lead in increased body burden of lead in Hartford children. *Environmental Health Perspectives*, 7, 99-102.

Levallois, P., Lavoie, M., Goulet, L., Nantel, A.J., and Gingras, S. (1991). Blood lead levels in children and pregnant women living near a lead-reclamation plant. *Canadian Medical Association Journal*, 144 (7), 877-885.

Lewis, R.G., Bond, A.E., et al. (1991, June 16-21). Determination of routes of exposure of infants and toddlers to household pesticides: A pilot study to test methods. Presented at the Air and Waste Management Association, Vancouver, BC.

Lewis, R.G. (1993, March 31) "Modified HVS3 sampler." [personal conversation]. Dr. Robert G. Lewis, Chief, Methods Research Branch, AREAL/ ORD, U.S. Environmental Protection Agency.

Lim, B.S., Schwemberger, J.G., Constant, P., and Bauer, K. (1995). Vacuum sampling of settled dust for lead analysis. Chapter 23 in Breen, J.J. and Stroup, C.R. (1995). Lead poisoning: exposure, abatement, and regulation. CRC Press, Inc.

Lioy, P.J., Freeman, N.C.G., Wainman, T., Stern, A.H., Boesch, R., Howell, T., and Shupack, S.I. (1992). Microenvironmental analysis of residential exposure to chromium-laden wastes in and around New Jersey homes, *Risk Analysis*, 12 (2), 287-299.

Lioy, P.J., Wainman, T., and Weisel, C. (1993). A wipe sampler for the quantitative measurement of dust on smooth surfaces: Laboratory performance studies. *Journal of Exposure Analysis and Environmental Epidemiology*, 3 (3), 315-330.

Matte, T.D., Figueroa, J.P., et al. (1989). Lead poisoning among household members exposed to lead-acid battery repair shops in Kingston, Jamaica. *International Journal of Epidemiology*, 18 (4), 874-881.

Matte, T.D. (1994, March and September). "Comments on lead risk assessment" in his peer review comments of this report.

McArthur, B. (1992). Dermal measurement and wipe sampling methods: A review. *Applied Occupational and Environmental Hygiene*, 7 (9), 599-606.

Menreath, B. (1991, August). "University of Cincinnati dust sampling method." [private conversation]. Bill Menreath, Researcher, Department of Environmental Health, University of Cincinnati, OH.

Midwest Research Institute. (1991, May 8). "Analysis of soil and dust samples for lead (Pb). Final report." Submitted to U.S. Environmental Protection Agency, Office of Toxic Substances.

Midwest Research Institute (1992, January). Engineering study to explore improvements in vacuum dust collection. Submitted to U.S. Environmental Protection Agency, Office of Toxic Substances.

Millson, M., Eller, P.M., and Ashley, K. (1994). Evaluation of wipe sampling materials for lead in surface dust. *American Industrial Hygiene Association Journal*, 55(4), 339-342.

Moffat, W.E. (1989). Blood lead determinants of a population living in a former lead mining area in southern Scotland. *Environmental Geochemistry and Health*, 11 (1), 3-8.

Midwest Research Institute (1993, October 30). Engineering study to explore improvements in vacuum dust collection. Report to the U.S. Environmental Protection Agency, Office of Toxic Substances.

National Institute for Occupational Safety and Health (1994, January 25). Close-out letter for HETA 92-052.

Needleman, H. and Scanlon, J. (1973). Getting the lead out. *New England Journal of Medicine*, 28, 466.

Occupational Safety and Health Administration: (1990). Sampling Surfaces for Surface Contamination. *Industrial Hygiene Technical Manual*, Chapter 2.

Pella, P. (1993, April 19). "XRF Dust Lead Analysis." [personal conversation]. Dr. Peter Pella, National Institute of Standards and Technology.

Prpic-Majic, D., Pongracic, J., Hrsak, J., and Pizent, A. (1992). A follow-up study in a lead smelter community following the introduction of an effective pollution control system. *Israel Journal of Medical Science*, 28(8-9), 548-556.

Que Hee, S.S., Peace, B., Clark, C.S., Boyle, J.R., Bornshein, R.L., and Hammond, P.B. (1985). Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. *Environmental Research*, 38; 77-95.

Que Hee, S.S. (1993, April 1). "University of Cincinnati dust sampling method." [private conversation]. Dr. Shane S. Que Hee, Professor of Environmental Health, UCLA.

Rabinowitz, M., Leviton, A., Needleman, H., Bellinger, D., and Waternaux, C. (1985). Environmental correlates of infant blood lead levels in Boston. *Environmental Research*, 38, 96-107.

Research Triangle Institute and Engineering Plus (1990, June 29). Development of a high volume small surface sampler. Final Report. EPA Contract No. 68-02-4544.

Rinehart, R.D. and Yanagisawa, Y. (1993). Para-occupational exposures to Pb and Sn carried by electric cable splicers. *American Industrial Hygiene Association Journal*, 54 (120), 593-599.

Roberts, J.W., Ruby, M.G., and Warren, G.R. (1987). Mutagenic activity of house dust. In *Short-Term Bioassays in the Analysis of Complex Environmental Mixtures* V. Plenum Press, New York and London.

Roberts, J.W. and Camens, D.E. (1989). Pilot study of a cotton glove press test for assessing exposure to pesticides in house dust. *Bulletin of Environmental Contamination and Toxicology*. 43: 717-724.

Roberts, J.W. and Ruby, M.G. (1989, January). Development of a high volume surface sampler for pesticides in floor dust. EPA 600/ 4-88/ 036.

Roberts, J.W., Camann, D.E., and Spittler, T.M. (1990, August). Monitoring and controlling lead in house dust in older homes. Indoor Air 90, Toronto. Proceedings from the 5th International Conference on Indoor Air Quality and Climate. D.S. Walkinshaw, ed., Canada Mortgage and Housing Corp., Ottawa.

Roberts, J.W., Budd, W.T., Ruby, M.G., Bond, A.E., Lewis, R.G., Weiner, R.W., and Camann, D.E. (1991). Development and field testing of a high volume sampler for pesticides and toxics in dust. *Journal of Exposure Analysis and Environmental Epidemiology*, 1 (2), 143-155.

Roberts, J.W., Bubb, W.T., et al. (1991, June 16-21). A small high volume surface sampler (HVS3) for pesticides and other toxic substances in house dust. Presented at the Air and Waste Management Association, Vancouver, BC.

Roberts, J.W. (1993, April 28). "House dust characteristics" [personal conversation]. Dr. John Roberts, Engineering Plus.

Roda, S. "DVM Laboratory Analysis Method." [personal conversation]. Sandy M. Roda, Director of Hematology and Environmental Laboratory. Institute of Environmental Health, Kettering Laboratory, 3223 Eden Avenue, Cincinnati, OH, 45267-0056.

Sayre, J.W., Charney, E., Vostal, J., and Pless, I. (1974) House and hand dust as a potential source of childhood lead exposure. *American Journal of Diseased Children*, 127, 167-170.

Sayre, J.W. and Katzel, M.D. (1979). Household surface lead dust: Its accumulation in vacant homes. *Environmental Health Perspectives*, 29, 179-182.

Schlecht, P.C. and Groff, J.H. (1994). ELPAT program report, background and current status. *Applied Occupational and Environmental Hygiene Journal*, 9(8), 529-536.

Seifert, B., Drews, M., and Aurand, K. (1984, August 20-24). Indoor heavy metal exposure of the population around a secondary lead smelter. World Health Organization/ et al. 3rd International Indoor Air Quality Climate Conference, Stockholm.

Solomon, R.L. and Hartford, J.W. (1976). Lead and cadmium in dusts and soils in a small urban community. *Environmental Science and Technology*, 10, 733-777.

Spittler, T.M. (1993, March 23). "Importance of particle size in assessing house dust lead exposure to children." [personal conversation]. Dr. Thomas M. Spittler, U.S.EPA Region I Laboratory.

Spittler, T.M. (1993, March 23). "Home owners' vacuum cleaners as a screening tool for lead dust." [personal conversation]. Dr Thomas M. Spittler, U.S. EPA Region I Laboratory.

Stark, A.D., Quah, R.F., Meigs, J.W., and DeLouise, E.R. (1982). The relationship of environmental lead to blood-lead levels in children. *Environmental Research*, 27, 372-383.

Stern, A.H., Freeman, N.C.G., Pleban, P., Boesch, R.R., Wainman, T., Howell, T., Shupack, S.I., Johnson, B.B., and Lioy, P.J. (1992). Residential exposure to chromium waste -- urine biological monitoring in conjunction with environmental exposure monitoring. *Environmental Research*, 58, 147-162.

Sussell, A. (1993, April 6). "Georgia Tech's Wipe Sampling Method." [personal conversation]. Aaron Sussell, Industrial Hygienist (Group Leader), National Institute for Occupational Safety and Health, Hazard Evaluation and Technical Assistance Branch, Cincinnati, OH.

Sussell, A., et al. (1993, May). NIOSH Health Hazard Evaluation Report. HETA 92-095-2317. Ohio University, Athens, OH.

Thornton, I., Davies, D.J.A., and Quinn, M.J. (1990). Lead exposure in young children from dust and soil in the United Kingdom. *Environmental Health Perspectives*, 89, 55-60.

United States Department of Housing and Urban Development. (1990, December 7). Comprehensive and workable plan for the abatement of lead-based paint in privately owned housing: a report to congress. Washington, DC.

United States Department of Housing and Urban Development. (1990). Lead-based paint: interim guidelines for hazard identification and abatement in public and Indian housing. Washington, DC. Appendix A.

United States Department of Housing and Urban Development. (1995, June). Guidelines for the evaluation and control of lead-based paint hazards in housing. Washington, DC: U.S. Department of Housing and Urban Development.

United States Environmental Protection Agency (1989, January). Project summary: Development of a high volume surface sampler for pesticides in floor dust, by J.W. Roberts and M.G. Ruby. EPA/ 600/ s4-88/ 036.

United States Environmental Protection Agency. (1991, May). Three-city soil-lead demonstration project. Midterm Project Update. Appendix A.

United States Environmental Protection Agency. (1994, July 14). Guidance on residential lead-based paint, lead-contaminated dust, and lead-contaminated soil. Memorandum from Lynn R. Goldman, Assistant Administrator of the Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency.

United States Environmental Protection Agency. (1995, February). Comprehensive abatement performance pilot study. Volume I: results of lead data analysis. EPA 747-R-93-007.

United States Environmental Protection Agency. (1995, in press). Laboratory evaluation of dust and dust lead recoveries for samplers and vacuum cleaners. Volume 1: Objectives, Methods, and Results. EPA 747-R-94-004A.

Vostal, J.J., Traves, E., Sayre, J.W., and Charney, E. (1974). Lead analysis of house dust: A method for the detection of another source of lead exposure in inner city children. *Environmental Health Perspectives,* 7, 91-97.

Wang, Y. (1994). The effect of vacuum collection efficiency and physical-chemical properties of household dust on lead exposure measurement. Abstract of the Dissertation. Environmental and Occupational Health Sciences Institute, University of New Jersey School of Dentistry and Medicine, 681 Frelinghuysen Road, P.O. Box 1179, Piscataway, NJ, 08855-1179.

Watt, J., Moorcroft, S., Brooks, K., Culbard, E., and Thornton, I. (1983, June 13-16). Metal contamination of dusts and soils in urban and rural households in the United Kingdom. Sampling and analytical techniques for households and external dusts. 17th Trace Substances in Environmental Health Conference, Columbia.

Westat and MRI (July 21, 1993). EPA/ OPPT quality assurance project plan for the wipe and vacuum study.

Whelan, E., Piacitelli, G., Gerwel, B., and Matte, T.D. (1994, May 5). Draft protocol: A study of take-home lead exposure among construction workers in New Jersey. National Institute for Occupational Safety and Health, Division of Surveillance, Hazards, and Field Studies, Industry Wide Studies Branch.