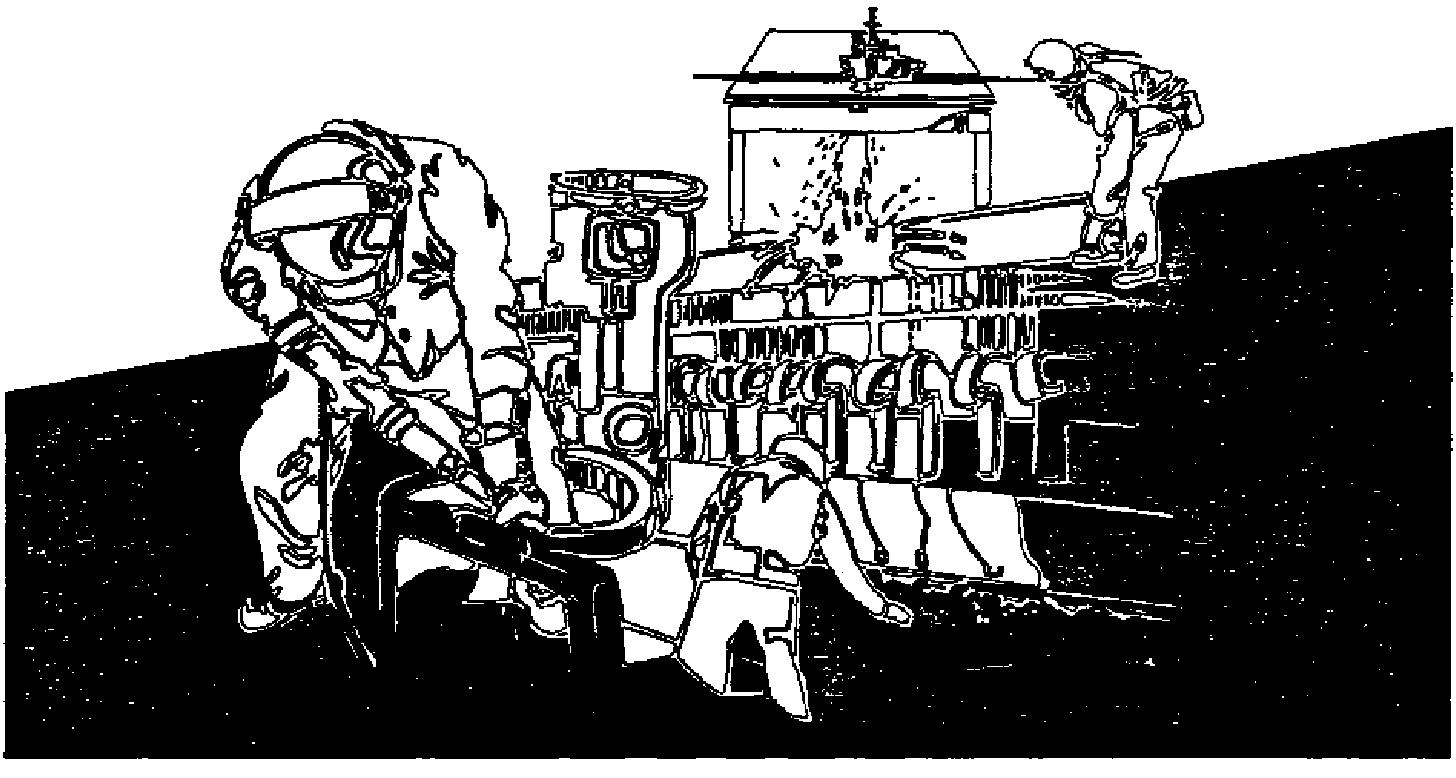
NIOSH

# HEALTH HAZARD EVALUATION REPORT

# HETA 90-070-2181
# HUD LEAD-BASED PAINT ABATEMENT DEMONSTRATION PROJECT



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

## PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

HETA 90-070-2181
FEBRUARY 1992
HUD LEAD-BASED PAINT ABATEMENT DEMONSTRATION PROJECT

NIOSH Investigators:
Aaron L. Sussell, M.P.H.
Larry J. Elliott, M.S.
Deanna Wild, M.S., M.B.A.
Eugene Freund, M.D., M.S.P.H

## I. SUMMARY

A request was received from the U.S. Department of Housing and Urban Development (HUD) Office for Policy Development and Research for a NIOSH Health Hazard Evaluation (HHE) to evaluate occupational safety and health hazards during the HUD Lead-Based Paint Abatement Demonstration. Lead-based paint and lead-contaminated house dust and soil are primary sources of childhood lead poisoning in residential settings. HUD was required to implement a lead-based paint abatement demonstration by amendments to the Lead-Based Paint Poisoning and Prevention Act (LPPPA) to compare costs and efficacy of various alternative methods of lead-based paint abatement.

This evaluation was of the first phase of the HUD demonstration; which was conducted in 172 vacant, single-family, HUD-owned homes located in Baltimore, MD; Washington, D.C.; Seattle and Tacoma, WA; Indianapolis, IN; Denver, CO and Birmingham, AL during 1989 and 1990. Abatement methods used in the HUD demonstration on interior and exterior lead-painted surfaces were abrasive removal, chemical removal, heat gun removal, encapsulation, enclosure, and replacement. Other activities were associated with all the primary abatement methods; these included precleaning, set up, (daily) cleaning, and final cleaning.

Nine NIOSH site visits were made in association with this HHE between 1989 and 1991; in Baltimore, Birmingham, Denver, and Indianapolis, and Washington, D.C. The purposes of the first eight visits were to make observations of abatement work and conduct environmental monitoring. The purpose of the last site visit was to present unresolved questions and interim recommendations based on preliminary analysis of environmental monitoring data to HUD representatives and principal contractors. To support the Health Hazard Evaluation, NIOSH obtained and analyzed data collected by HUD contractors during the demonstration; including 2635 air samples, 455 pre-and post-abatement paired soil samples, and 19,373 paint lead concentration measurements.

Results of NIOSH air sampling by abatement method indicated that time-weighted average (TWA) exposures to lead were highest during the heat gun method (range: not detected - 286 micrograms per cubic meter ($\mu g/m^3$)). NIOSH observations and limited measurements did not indicate that the 700°F temperature placed on heat guns was an effective control for worker exposures,

although the results were not conclusive. During the heat gun method exposures to volatile organic compounds, including hexanes, *n*-butanol, toluene, xylene isomers, butyl ether, and siloxanes were low (not detected - 0.47 milligrams per cubic meter ($mg/m^3$)). Exposures to lead were relatively low during other abatement methods (range: not detected -36 $\mu g/m^3$). In houses contained with plastic, the use of propane heaters without adequate ventilation for even short periods (1-2 hours) resulted in significantly elevated exposures to carbon dioxide ($CO_2$) and carbon monoxide (CO). Surface dust sampling at one housing unit undergoing abatement found an area designated and utilized as a "clean" staging area by the contractor was contaminated with lead. Facilities for personal hygiene were generally inadequate.

An analysis of variance (ANOVA) of HUD personal and area air sampling results indicated airborne lead concentrations varied significantly among abatement methods, contractors (with significant method-contractor interaction), and housing units. The observed variations between contractors, and the contractor-method interaction were consistent with work practices as an important determinant of lead exposures. An analysis of covariance (ANCOVA) of the mean (personal and area) airborne lead concentrations by housing unit found that the abatement strategy, the mean pre-abatement soil lead concentration, and the mean paint lead concentration were significant variables. Total square feet abated, contractor, city, or median paint condition rating were not significant variables for the mean airborne lead concentrations by housing unit.

The personal exposures to airborne lead were generally low (geometric mean 3.1 $\mu g/m^3$), but the variability of exposures was high (geometric standard deviation 4.4). Maximum personal and general area airborne lead concentrations were 916 $\mu g/m^3$ and 1296 $\mu g/m^3$, respectively. Personal airborne lead concentrations exceeding the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 50 $\mu g/m^3$ were measured for eight of eleven NIOSH-assigned abatement method categories. However, less than 5% of the personal exposures to lead measured for chemical removal, cleaning, enclosure, and replacement methods; and none of the exposures for encapsulation, final cleaning, and precleaning methods exceeded the OSHA PEL of 50 $\mu g/m^3$.

Pre- and post-abatement soil sampling indicated that lead paint abatement in some cases resulted in increases in soil lead levels one to three feet from the exterior walls. The mean soil lead concentrations increased in 96 (74%) of the 130 abated units reported; however, only 8 (6%) of the unit mean increases (range: 44-470 parts per million) reached statistical significance ($p < 0.05$). An analysis of covariance indicated that the mean change in soil lead concentration by housing unit did not vary significantly with city, contractor, total exterior square feet abated, mean paint lead concentration, abatement strategy and median paint condition.

No correlation between mean airborne lead and mean change in soil lead concentration was observed in results for 128 abated units ($r^2=0.016$); indicating that observed changes in soil lead concentration were not due primarily to airborne lead concentrations.

Recommendations are presented for improved training, emphasis on proper work practices and engineering controls, prevention of safety hazards, initial risk assessment of housing units, personal hygiene facilities, respiratory protection programs, medical monitoring and surveillance (see Section VIII, pages 37-40). HUD should conduct additional research to determine effective method-specific engineering controls, containment procedures, and work practices to minimize lead exposures, and lead contamination during abatement.

The evaluation indicated that workers are potentially overexposed to lead, and encounter a number of safety hazards during residential lead abatement. Although mean airborne lead exposures were low, overexposures were measured during abrasive removal, chemical removal, heat gun, cleaning, enclosure, and other abatement methods. Airborne lead exposures varied significantly between abatement methods, contractors, and abated housing units. Recommendations for minimizing employee exposures to lead, and improved medical monitoring and surveillance are presented in this report.

KEYWORDS: SIC 1521 (General building contractors-single-family houses) lead, lead abatement, single-family houses, public housing, abatement workers, construction, HUD.

## II. INTRODUCTION

A request was received from the HUD Office for Policy Development and Research for a NIOSH Health Hazard Evaluation (HHE) to evaluate worker exposures to lead and other occupational hazards during the HUD Lead-Based Paint Abatement Demonstration. In recent years, compelling scientific evidence has accumulated showing adverse health effects of lead exposure in children at blood lead levels previously thought to be safe. Lead-based paint, and lead-contaminated soils and house dust, have been found to be primary sources of childhood lead poisoning.

HUD was required to implement a lead-based paint abatement demonstration by amendments to the Lead-Based Paint Poisoning and Prevention Act (LPPPA) in 1987 and 1988. Primary objectives of the demonstration were to compare costs and efficacy of various alternative methods of lead-based paint abatement. The NIOSH evaluation was of the first part of the demonstration, which was conducted in vacant, single-family homes which HUD had obtained due to foreclosures of Federal Housing Administration (FHA) mortgages. In August 1991, HUD published its findings on the FHA portion of the lead-based paint abatement demonstration, which will be referred to as the HUD demonstration in this report.[1] A second phase of the demonstration, conducted in multiple-family public housing, was not included in the NIOSH evaluation.

The HUD demonstration took place in 172 vacant housing units located in Baltimore, MD; Washington, D.C.; Seattle and Tacoma, WA; Indianapolis, IN; Denver, CO and Birmingham, AL. The HUD demonstration was conducted under a primary contractor (Dewberry & Davis) which was responsible for management of all abatement work, supervision, and preparation of final reports. Subcontractors performed other functions including research design and data analysis (Speedwell, Inc.); testing paint lead concentrations (KTA-Tator, Inc.); and worker safety and health, personal monitoring, and environmental monitoring (Tracor Technology Resources, Inc.).

Nine NIOSH site visits were made in association with this HHE between 1989 and 1991; (1) Birmingham, 1989; (2,3) Denver, October 31, and November 3, 1989; (4,5) Indianapolis, November 20, and December 4-6, 1989; (6) Baltimore, February 1, 1990; (7,8) Indianapolis, February 15-16, and March 14-16, 1990; and (9) Washington, D.C., March 14, 1991. The purposes of the first eight visits were to make observations of abatement work and conduct environmental monitoring. After the first six visits, an interim report dated February 16, 1990, with preliminary observations and recommendations was provided to HUD. In October 1990, NIOSH received data for more than 2600 air samples collected and compiled by HUD's principal contractors (Tracor Technology Resources, Inc. and Speedwell, Inc.). The purpose of the last site visit was to present unresolved questions and interim recommendations based on our preliminary analysis of NIOSH and HUD data to HUD representatives and principal contractors.

A second interim report (dated March 21, 1991) was provided to HUD which included discussion of unresolved questions regarding specific aspects of lead abatement including feasibility of engineering controls, effectiveness of proper hygiene facilities or work practices to control exposures, effectiveness of containment procedures, appropriate respiratory protection, and the long-term effectiveness of methods.

To attempt to address some of the unresolved questions regarding abatement work in the HUD demonstration, additional environmental data and field notes collected by HUD contractors were requested. HUD and it's principal contractor (Dewberry & Davis) subsequently (April 8, 1991) notified NIOSH that certain portions of the requested data had not been compiled or organized, and that NIOSH would need to provide significant additional labor expenses to obtain those portions of data. NIOSH subsequently requested the additional data that could be provided without additional resources. This data (received in July 1991) included results for air monitoring during various abatement methods, pre- and post-abatement composite soil sampling, measurement of paint lead concentrations, and ratings of paint condition. Data which were requested for this evaluation, but not provided due to reported resource constraints were: work histories for workers with blood lead level (BLL) increases of 10 micrograms per deciliter ($\mu$g/dL) or greater; air sampling times (minutes), interior or exterior location for air samples; specific work practices and ventilation associated with the highest airborne exposures for each method.

## III. BACKGROUND

The adverse health effects of lead exposure among children are a major public health problem. The Agency for Toxic Substances and Disease Registry estimated that in 1984, 17% of all American preschool children had blood lead levels greater than 15 micrograms per deciliter (a level at which the Centers for Disease Control currently recommends intervention).[2] Prevention of childhood lead poisoning is the primary reason for performing lead abatement in public or private housing. Over the past several decades, Federal and state regulatory action has resulted in substantial progress in reducing blood lead levels in the entire U.S. population by reducing lead concentrations in air, drinking water, food, and consumer paints. However, lead-based paint and lead-contaminated dusts and soils remain, and are the primary sources of lead exposure for children. These sources affect children more than adults due to frequent hand-to-mouth contact in young children and because nearly 50% of ingested lead is absorbed in children, significantly more than in adults.

Abatement strategies and methods in the HUD demonstration were based on guidelines developed by the National Institute of Building Sciences (NIBS) under a contract with HUD.[3] Additionally, during the demonstration HUD released a comprehensive set of guidelines for lead abatement based on the NIBS guidelines entitled *Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing*.[4]

The three general strategies used for lead-based paint abatement were replacement, encapsulation, and paint removal; each was comprised of one or more abatement methods. The abatement methods used in the HUD demonstration on interior and exterior surfaces were abrasive removal, chemical removal, heat gun removal, encapsulation, enclosure, and replacement.

<u>Abrasive removal</u> involved removal of paint with sanders, needle-guns, or other mechanical equipment; all were fitted with a high-efficiency particulate air (HEPA) filter dust collection system.

<u>Chemical removal</u> involved removal of paint with chemical stripping mixtures which were applied, allowed to dissolve or soften paint, and then scraped off. Chemical strippers which dissolve paint are either caustic or solvent-based; in the demonstration, only caustic chemical strippers were used.

<u>Heat gun removal</u> involved removal of paint by first softening and loosening paint with an electric hand-held heat gun, followed by hand scraping with a putty knife or similar tool. The paint was softened, or delaminated from the substrate, by directing the stream of heated air from the gun nozzle on the painted surface. Commercial heat guns can typically produce air temperatures of approximately 1000°F at the gun nozzle. Based on a recommendation in the NIBS guidelines, a 700°F temperature restriction was placed on heat guns (nozzle temperature) in the HUD demonstration.

<u>Encapsulation</u> involved sealing painted surfaces with durable coatings (for example, polymer materials) which were resistant to delamination, cracking, peeling, algae, and fungus. Household paints and contact paper or paper wall

coverings were **not** considered to be acceptable encapsulants under the NIBS guidelines.

Enclosure was defined as an encapsulation strategy that involved covering painted surfaces with mechanically affixed, durable building materials such as gypsum board or wood; followed by caulking or sealing of seams and joints to prevent escape of lead-containing materials or dust.

Replacement involved removing entire building components (i.e., windows, doors, baseboards) that had been lead painted and replacing them with new components which were free of lead-based paint.

In the HUD Demonstration, other activities were required daily, prior to, or after primary abatement for each abatement method; these included precleaning, set up, (daily) cleaning, and final cleaning. For simplicity, in discussion of sampling results these activities will also be referred to as abatement methods later in this report. The definitions for the terms used are as follows:

Precleaning was the preliminary cleanup of lead contamination or debris in a housing unit, which may involve vacuuming with a special HEPA-filter equipped vacuum ("HEPA vacuuming"), sweeping, and/or removal of furniture or carpeting. According to the project protocol, prior to sweeping or vacuuming, dust and debris were to be misted with water to reduce airborne dust generation.

Set up included activities required for initial set up of the abatement job; which were: construction of 2-stage entry/exit and decontamination structures; laying, and securing 6-mil plastic sheeting on interior surfaces and exterior surfaces within 6 feet of walls; sealing windows, doors, fixtures, and air supply or return vents with 6-mil plastic sheeting.

Cleaning included daily clean up activities during abatement, consisting of wrapping large debris in 6-mil plastic, sweeping, HEPA vacuuming, and bagging small debris and fines in plastic. According to the project protocol, prior to sweeping or vacuuming, dust and debris were to be misted with water to reduce airborne dust generation.

Final cleaning included folding, sealing, and removal of plastic sheeting used for containment; and repeated HEPA-vacuuming and mopping with tri-sodium phosphate solution to achieve specified clearance standards for surface dust following abatement. Plastic sheeting, dust and debris were to be misted with water to reduce dust before handling.

## IV. EVALUATION DESIGN AND METHODS

### Environmental data collected by NIOSH

NIOSH investigators conducted site visits at FHA houses undergoing lead abatement in Denver, Indianapolis, Baltimore, and Birmingham from October 1989 to March 1990. NIOSH did not attempt to duplicate or verify the extensive environmental monitoring HUD performed in each city through its principal contractors. NIOSH environmental monitoring in the Demonstration was limited, and intended to complement data collected by HUD contractors. The emphasis of air sampling conducted by NIOSH was to characterize exposures by abatement method to allow a determination of the degree of hazard and appropriate controls for each method. Worker exposure to airborne lead was the primary hazard of concern and was evaluated by collecting personal breathing zone (PBZ) and area air samples. Other exposures to airborne compounds were evaluated, including alkaline dust, and volatile organic compounds (VOCs). To assess potential worker exposures via ingestion, surface wipe samples for lead were collected. Environmental sampling also included sampling bulk materials (e.g., paint chips) in some cases.

Workers observed typically performed one or more of the following lead abatement methods or techniques in a workshift: abrasive removal, chemical removal, cleaning, encapsulation, enclosure, final cleaning, precleaning, replacement, set up, or other tasks. PBZ and area sampling were during periods of work activity by abatement method; sampling times were typically of 1-3 hours duration. During sampling periods, work practices were observed.

NIOSH analytical methods referenced below are described in the *NIOSH Manual of Analytical Methods, Third Edition*.[5] Each of the laboratory methods described below has a limit of detection (LOD) and limit of quantitation (LOQ) specific to that method. The respective LOD and LOQ for each laboratory analysis were determined in the laboratory and are reported with the sampling results in tables later. In the case of direct-reading instruments the manufacturer's LOD was reported. Results reported as not detected (ND) were below either the LOD or LOQ, as indicated.

1. Air Samples

Area and PBZ air samples were collected with sampling media connected via Tygon® tubing to Gillian® battery-operated personal sampling pumps. The high-flow pumps were calibrated immediately before and after sampling with a Kurz

Pocket Flow Calibrator® mass flowmeter, which had been previously calibrated with a primary standard (bubble flowmeter). The mean of the pre- and post-sampling flow rate measurements was used to calculate air sample volumes.

The analytes, initial pump flow rates, sample collection media, and methods of analysis for the samples are listed below.

Lead: flow rate of 2 liters per minute (ℓ/min) through 37-millimeter (mm), 0.8-micron (μm) pore size, cellulose ester membrane filters in closed-face cassettes, analysis by atomic absorption spectroscopy (AAS) with flame--NIOSH Method 7082. In some cases, to obtain a significantly lower LOD and LOQ, AAS with a graphite furnace was used--NIOSH Method 7105.

Volatile Organic Compounds (VOCs): flow rate of 0.2 ℓ/min through charcoal sorbent tubes (coconut shell, 100 milligrams (mg) front/50 mg back), subsequent desorption with carbon disulfide and qualitative analysis by gas chromatography-mass spectrometry (GC/MS). In some cases, the primary VOCs detected by qualitative analysis of samples were subsequently quantitatively analyzed in separate samples (collected simultaneously) by gas chromatography, flame-ionization detector (GC/FID)--NIOSH Method 1500.

Alkaline Dusts: flow rate of 2 ℓ/min through 37-mm, 1-μm pore size PTFE membrane filters in closed-face cassettes, analysis by acid-base titration--NIOSH Method 7401.

Phthalates: flow rate of 2 ℓ/min through 37-mm, 0.8-μm pore size, cellulose ester membrane filters in closed-face cassettes, qualitative analysis by gas chromatography, flame-ionization detector (GC/FID) according to NIOSH Method 5020.

Other: Grab, or instantaneous, air samples for carbon dioxide ($CO_2$), and carbon monoxide (CO) were collected with Dräger® detector tubes (0.01%/a and 5/c tubes, respectively) and the manufacturer's hand-operated bellows pump. The concentration was read directly from the length of colored stain on the graduated tubes immediately after sampling.

Heat gun temperatures were measured with a Thermolyne® Type PM 20700 digital pyrometer (with air temperature probe), which provided nearly instantaneous readings of air temperatures. The instrument used had a temperature range of -50°F to 1999°F, and was factory calibrated to a reported accuracy of ±0.5% and resolution of 1°F. Heat gun temperatures were measured by periodically placing the air temperature probe within 1 cm of the end of the gun nozzle, at the center of the nozzle. Temperature ranges are reported for the guns, due to rapid variations of measured temperatures during actual operating conditions.

2. Bulk Samples

Lead in Soil and Paint: Bulk samples of surface soil and paint were collected by transferring 1-10 grams of material into clean 20-ml glass vials or new sealable plastic bags with disposable wooden tongue depressors. Samples were ground with a mortar and pestle prior to taking aliquots for analysis. A weighed portion of each sample was digested with nitric acid, perchloric acid and 30% hydrogen peroxide, dissolved in dilute nitric acid, and quantitatively transferred to a volumetric flask (10-25ml). Subsequent analysis for lead was by AAS--NIOSH Method 7082, or inductively-coupled plasma atomic-emission-spectrometry (ICP-AES)--NIOSH Method 7300.

Lead in Surface Dust: Samples were collected using commercial pre-moistened baby wipes using a modification of the "Laboratory Testing for Lead in Dust" procedure contained in the HUD publication *Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing*. Surface dust samples were collected by:

a) measuring and marking a surface area of one square foot ($ft^2$) or other known size

b) donning a fresh pair of disposable gloves

c) taking a wipe from the container (the first wipe each day was discarded)

d) folding the wipe in half and wiping the entire marked area with a series of horizontal strokes in an "S"-pattern (the wipe is not lifted)

e) refolding the wipe with the dust side in and wiping the area in an "S"-pattern a second time at a 90° angle to the first pattern

f) folding the wipe again and wiping the area a third time in an "S"-pattern at a 90° angle to the previous pattern

g) placing the folded baby wipe in a new sealable plastic bag

h) discarding the disposable gloves

Care was taken to use the same technique and wiping pressure for each sample to reduce variation in collection efficiency, and to reduce potential cross-contamination of areas sampled. The samples were digested with nitric acid, perchloric acid and 30% hydrogen peroxide, dissolved in dilute nitric acid, and quantitatively transferred to 25 ml volumetric flasks. Subsequent analysis for lead was by AAS–NIOSH Method 7082.

Asbestos: Bulk samples for asbestos were collected by wetting a portion of the material in-place with water mist, removing a small portion of material (1-5 grams) with minimal disruption of the parent material, and storage of the sample in a sealed plastic container. The samples were subsequently analyzed by polarized light microscopy (PLM) with dispersion staining according to NIOSH Method 9002.

Heated Paint Samples, Thermal Decomposition Products (VOCs): Paint chips were collected at a house undergoing abatement. Portions of each sample were heated in a tube furnace operating at 680-720°F (360-380°C), to simulate heat gun nozzle air temperatures in the Demonstration (which were restricted to 700°F). Effluents were sampled with both activated charcoal and ORBO®-23 sorbent tubes at a flow rate of approximately 0.060 ℓ/min for 30 to 60 minutes. The charcoal tubes were desorbed with 1 ml carbon disulfide, and analyzed in the same fashion as other air samples for VOCs (see air samples above)–NIOSH Method 1500. The ORBO tubes were qualitatively analyzed for aldehydes according to NIOSH Method 2539.

**Environmental-data collected by HUD contractors**

The research design and methods utilized by HUD contractors to collect environmental data are described in *The HUD Lead-Based Paint Abatement Demonstration (FHA)* report and its appendices.[1]

A principal HUD sub-contractor (Tracor Technology Resources, Inc.) was responsible for developing worker protection protocols, conducting safety and health training, and performing air sampling for lead. According to the managing contractor's (Dewberry & Davis) original study design, 31 personal and area air samples were to be collected in each housing unit during abatement activities. Fewer samples were actually collected in some units with scheduled work of relatively short duration. Workers typically performed one or more of the following lead abatement methods or techniques in a workshift: abrasive removal, chemical removal, cleaning, encapsulation, enclosure, final cleaning, precleaning, replacement, set up, or other tasks. PBZ and area air sampling were during periods of work activity by abatement method, sampling times were generally less than 8-hours. Tracor employed different personnel in the various cities of the FHA Demonstration to conduct air sampling. All the air samples were analyzed by the contractor's in-house laboratory using AAS--NIOSH Method 7082.

HUD contractors collected composite soil samples along four exterior walls of abated units pre- and post-abatement. The composite samples were from five individual samples that were collected from one to three feet from the base of each exterior wall of the housing units. By convention, the samples collected for the wall facing the street were designated "wall 1," and walls 2, 3, and 4 in clockwise rotation.

The initial screening of paint lead concentrations in 304 FHA single-family homes was conducted in-place with direct reading instruments; x-ray fluorescence (XRF) analyzers. Based on these test results and a stratified random sampling design, 172 housing units were selected by HUD for abatement. In units to be abated, follow-up testing was performed for painted substrates with XRF results between 0.2 and 1.8 $mg/cm^2$; as XRF analyzers have relatively poor precision and accuracy for lead concentrations near 1 $mg/cm^2$. These criteria for follow-up testing of XRF analyzer results were based on research conducted by the National Institute of Standards and Technology for HUD in 1989.[6] The results of 19,373 paint lead concentration measurements by AAS or XRF were provided to NIOSH for analysis; of these 5774 (30%) were AAS results.

To allow comparison and interchangeability of AAS and XRF results, all of the AAS results were converted from parts per million (ppm) (weight/weight) to $mg/cm^2$ (weight/unit area). To make this conversion it was necessary to accurately measure the surface areas for all paint samples collected for AAS. For those painted surfaces with both XRF and AAS measurements provided, NIOSH used only the AAS results due to the greater accuracy and precision of AAS.

To determine the important variables affecting air lead and post-abatement soil lead concentrations during abatement, NIOSH performed an analysis of variance (ANOVA) and two analyses of covariance (ANCOVA) using airborne lead concentration, log mean airborne lead concentration by housing unit, and mean change in soil lead concentration by housing unit as the respective dependent variables. A summary of the NIOSH analyses is presented in Figure 1; the criteria used for statistical significance was $p<0.05$. The number of categories or observations for the variables used in the analyses are presented in Results and

Discussion, Section VI (see pages 20-32). Due to the high percentage of missing observations, the variable indicating whether the air sampling locations were interior or exterior ("room") was not included in these analyses.

**Medical-data collected by HUD contractors**

Collection of sufficient data to assess worker exposure to lead was required by HUD's protocol for medical monitoring as described in *The HUD Lead-Based Paint Abatement Demonstration (FHA)* report and appendices.[1] The medical monitoring protocol called for a BLL test prior to a worker's commencing abatement work; every two months for the first six months; and then at six month intervals thereafter. All BLL analyses were performed by an OSHA-approved laboratory. Data collected included employee name, date, employer name, city, and BLL. The protocol called for removal from lead abatement work when a worker's BLL exceeded 25 micrograms per deciliter of whole blood (µg/dl), equivalent to 1.20 micromoles per liter of blood (µmol/l). The protocol did not address the issue of whether workers were entitled to continued compensation while in medical removal status.

Records compiled by the prime contractor (Dewberry and Davis) were the exclusive source of blood lead level (BLL) data for this project. In many cases, the abatement contractors were not successful in complying with follow-up medical monitoring of workers during the demonstration.

## V. EVALUATION CRITERIA

**General guidelines**

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators employ environmental evaluation criteria for assessment of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours/day, 40 hours/week for a working lifetime without experiencing adverse health effects. It is important to note, however, that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the levels established by the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus the overall exposure may be increased above measured airborne concentrations. Evaluation criteria typically change over time as new information on the toxic effects of an agent become available.

The primary sources of evaluation criteria for the workplace are: NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[7] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[8] and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[9] These values are usually based on a time-weighted average (TWA) exposure, which refers to the average airborne concentration of a substance over an entire 8- to 10-hour workday. Concentrations are usually expressed in parts per million (ppm), milligrams per cubic meter ($mg/m^3$), or micrograms per cubic meter ($\mu g/m^3$). In addition, for some substances there are short-term exposure limits or ceiling limits which are intended to supplement the TWA limits where there are recognized toxic effects from short-term exposures.

For specific substances NIOSH recommendations or the ACGIH TLVs may be lower than the corresponding OSHA standards, as they are based primarily on the prevention of occupational disease. In contrast, OSHA PELs and other standards are required to take into account the economic feasibility of reducing exposures in affected industries, public notice and comment, and judicial review. In evaluating worker exposure levels and NIOSH recommendations for reducing exposures, it should be noted that employers are legally required to meet the requirements of OSHA standards.

**Specific substances**

Carbon Monoxide (CO)

Carbon monoxide is a colorless, odorless gas that commonly results from combustion of hydrocarbon-based fuels. Exposure to carbon monoxide (CO) decreases the ability of the blood to carry oxygen to the tissues. Overexposure to CO may cause headache, nausea, dizziness, weakness, rapid breathing, unconsciousness, and eventually death. High concentrations may be rapidly fatal without producing significant warning symptoms. The effects are more severe in pregnant women, people who are working at an accelerated pace, and at elevated temperatures or at altitudes above 2,000 ft. The NIOSH REL for CO is 35 ppm as a TWA for up to 10 hours, with a ceiling limit of 200 ppm.

Carbon Dioxide ($CO_2$)

Carbon dioxide ($CO_2$) is a colorless, odorless gas, which results from combustion of hydrocarbon-based fuels, respiration in living things, and the sublimation of solid $CO_2$ ("dry ice"). Overexposure to $CO_2$ may cause headache, dizziness, shortness of breath, and eventually death by asphyxiation. The NIOSH REL for $CO_2$ is 5000 ppm as a TWA for up to 10 hours per day; the OSHA PEL is 10,000 ppm as an 8-hour TWA.

$CO_2$ is a primary constituent of human exhaled breath; its concentration in indoor occupied spaces is often used as an indicator of whether adequate quantities of fresh air are being supplied. In occupied areas of buildings, $CO_2$ concentrations are normally higher than the ambient outdoor $CO_2$ concentrations (which are typically about 350 ppm). The American Society of Heating, Refrigerating, and Air-Conditioning Engineer's (ASHRAE's) Ventilation Standard, ASHRAE 62-1989, *Ventilation for Acceptable Indoor Air Quality*, recommends outdoor air supply rates be maintained so that the concentration of $CO_2$ does not exceed 1000 ppm in occupied areas.[10] When indoor $CO_2$ concentrations exceed 1000 ppm in areas where the only known source is building occupants, inadequate ventilation is suggested. Elevated $CO_2$ concentrations indicate that other indoor contaminants (such as volatile organic compounds) may also be increased.

Lead-occupational exposure

Inhalation (breathing) of dust and fume, and ingestion (swallowing) resulting from hand-to-mouth contact with lead-contaminated food, cigarettes, clothing, or other objects are the major routes of worker exposure to lead. Once absorbed, lead accumulates in the soft tissues and bones, with the highest accumulation in the liver and kidneys.[11] It is stored in the bones for decades, and may cause toxic effects as it is slowly released over time. Overexposure to lead results in damage to the kidneys, gastrointestinal tract, peripheral and central nervous systems, and the blood-forming organs (bone marrow).

The frequency and severity of symptoms associated with lead exposure increase with increasing blood lead levels (BLLs). Signs or symptoms of lead intoxication include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort, colic, anemia, high blood pressure, irritability or anxiety, fine tremors, and "wrist drop."[12,13,14]

Overt symptoms of lead poisoning in adults generally begin at BLLs between 60 and 120 $\mu g/dl$.[10] Neurologic, hematologic, and reproductive effects, however, may be detectable at much lower levels, and the World Health Organization (WHO) has recommended an upper limit of 40 μg/dl for occupationally exposed adult males.[15] The mean serum lead level for U.S. men 1976-1980 was 16 μg/dl;[16,17] however, with the implementation of lead-free gasoline and reduced lead in food, the 1991 average serum lead level of U.S. men will probably drop below 9 μg/dl.[18]

An increase in an individual worker's BLL can mean that the worker is being overexposed to lead, and that engineering controls, respiratory protection, or work practices are inadequate. While the BLL is a good indication of recent exposure to, and current absorption of lead, it is not a reliable indication of the total body burden of lead.[19] Lead can accumulate in the body over time and produce health effects long after exposure has stopped. Long-term overexposure to lead is may cause infertility in both sexes, fetal damage, chronic kidney disease (nephropathy), and anemia.

The workplace is not the only source of exposure; lead is a trace element in foods and beverages and may be a contaminant in drinking water, ambient air, soil, and street or house dust. Adults consume approximately 300 μg of lead each day, of which only approximately 10% is absorbed. The average daily respiratory intake for adults living in the United States is 20 μg.[20,21] In non-industrial environments, the greatest single source of lead in air has typically been automobile exhaust, but this source has been greatly reduced in the United States.

The OSHA lead standard for general industry specifies a PEL of 50 $\mu g/m^3$ as an 8-hour TWA for daily exposure to (airborne) lead. The standard requires semi-annual monitoring of BLL for employees exposed to airborne lead at or above the Action Level of 30 $\mu g/m^3$ (8-hour TWA), and specifies medical removal of employees whose average blood lead is 50 μg/dl or greater. Provision for economic protection of medically removed workers is included in the standard.[22] The construction industry (which includes lead abatement workers) was exempted from this regulation when it was promulgated in 1978. The current OSHA standard for the construction industry has a PEL for lead of 200 $\mu g/m^3$ (8-hr TWA), and does not require medical monitoring or medical removal.

The NIOSH REL for lead exposure is less than 100 $\mu g/m^3$ as a TWA up to 10 hours, in order that worker's BLLs remain below 60 μg/dl. NIOSH is presently reviewing current literature on the health effects of lead exposure to re-evaluate its REL.

Recent studies suggest that there are adverse health effects at BLLs below the current acceptable levels for persons with occupational exposure. A number of studies have found neurological symptoms in workers with BLLs of 40 to 60 µg/dl. Male BLLs are associated with increases in blood pressure, with no apparent lower threshold of effect. Studies have suggested decreased fertility in men at BLLs as low as 40 µg/dl. Prenatal exposure to lead is associated with reduced gestational age and birthweight, and delayed early mental development at prenatal maternal BLLs as low as 10 to 15 µg/dl.[23]

In recognition of the health risks associated with exposure to lead, goals for reducing occupational exposure were specified in *Healthy People 2000*, a recent statement of national consensus and U.S. Public Health Service policy for health promotion and disease prevention. The goal for workers exposed to lead is to eliminate, by the year 2000, all exposures that result in BLLs greater than 25 µg/dl.[24]

NIOSH and OSHA have recently published recommendations for construction workers potentially exposed to lead.[25,26] Prior to job placement, these workers should receive a complete baseline health evaluation from an examining physician which includes medical and work histories; a physical examination; and appropriate physiologic and laboratory tests (pulmonary status, blood pressure, blood testing, urinalysis, etc). Findings of this examination unrelated to lead exposure must not be revealed to the employer. Engineering and work practice controls should be used to reduce employee exposures below the OSHA PEL for general industry (50 µg/m$^3$, 8-hr TWA). Medical notification and medical removal as specified in the OSHA general industry standard should be applied to construction workers.

Lead-childhood exposure

The adverse affects of lead on children and fetuses include decreases in intelligence and brain development, developmental delays, behavioral disturbances, decreased stature, anemia, elevated erythrocyte protoporphyrin levels, decreased gestational weight and age, and miscarriage or stillbirth. Lead exposure is especially devastating to fetuses and young children due to potentially irreversible toxic effects on the developing brain and nervous system.[27]

The Centers for Disease Control (CDC) recently (October 1991) published the fourth revision of *Preventing Lead Poisoning in Young Children* in recognition of new data indicating adverse effects in children at blood lead levels previously believed to be safe (e.g., 25 µg/dl).[28] No threshold has been identified for the harmful effects of lead in children; the CDC currently recommends a multitier approach to defining and preventing childhood lead poisoning, based on BLL screening. The BLLs and corresponding actions which CDC has recommended are: $\geq 10$ µg/dl, community prevention activities; $\geq 15$ µg/dl, individual case management including nutritional and educational interventions and more frequent screening; $\geq 20$ µg/dl, medical evaluation, environmental investigation and remediation. Additionally, environmental investigation and remediation are recommended for BLLs of 15-19 µg/dl, if such levels persist. The U.S. Public Health Service Year 2000 Objectives for the Nation aim for progressive declines in the number of lead poisoned children, leading to the elimination of this preventable disease.[29]

In homes with a family member occupationally exposed to lead, lead dust may be carried home on clothing, skin, and hair, and in vehicles. High BLLs in resident children, and elevated concentrations of lead in the house dust, have been found in the homes of workers employed in industries associated with high lead exposure.[30] Particular effort should be made to ensure that children of workers with lead poisoning, or who work in areas of high lead exposure, are tested for lead exposure (BLL) by a qualified health-care provider.

Lead in surface dust

There are currently no Federal standards governing the level of lead in surface dust in either occupational or environmental (i.e., residential) settings. However, lead-contaminated surface dust in either setting represents a potential exposure to lead through ingestion for children and adults. This may occur either by direct hand-to-mouth contact with the dust, or indirectly from hand-to-mouth contact via clothing, cigarettes, or food which have been contaminated by lead-containing dust. Previous studies have found a significant correlation between resident children's BLLs and house dust lead levels.[31] Based on previous standards established in Massachusetts and Maryland to prevent lead poisoning of young children in residences, HUD has established interim standards for final clearance after lead abatement in residences. These criteria were not based on health risk assessment, but were empirically established as feasible limits for clearance following final cleaning during residential lead-based paint abatement. The HUD Guidelines specify a surface dust wipe sampling method and the following lead limits for final clearance after abatement, expressed as micrograms per square foot ($\mu g/ft^2$):

floors, 200 $\mu g/ft^2$

window sills, 500 $\mu g/ft^2$

window wells, 800 $\mu g/ft^2$

Additionally, HUD recommends that the standard for floors also be applied to exterior porches.[2] HUD recommends the use of these criteria until they are refined or replaced through additional research.

Lead in soil

There are no Federal standards for occupational or childhood exposure to lead in soil. The CDC has previously stated (*Preventing Lead Poisoning in Young Children*--1985 edition) that soil concentrations exceeding 500-1,000 ppm appeared to cause increased BLLs in children. Based on this recommendation, the U.S. Environmental Protection Agency (EPA) Offices of Emergency and Remedial Response and Waste Programs Enforcement currently use an interim guideline for Superfund hazardous waste sites which specifies cleanup of soil to a total lead concentration in the range of 500 to 1000 ppm.[32]

The State of Minnesota has promulgated a standard applicable to lead in soil on residential property and playgrounds intended to prevent exposures that might result in elevated (>25 $\mu g/dl$) childhood BLLs. The standard was based on a health risk assessment model intended to provide a reasonable degree of protection for young children considering the potential contribution of soil and other sources of lead exposure such as paint and house dust. The standard requires abatement for total lead concentrations at or above 0.03 percent by weight (300 ppm) of soil.[33]

Sodium hydroxide

Sodium hydroxide (NaOH), also known as caustic soda or lye, is the active ingredient in many caustic strippers used for lead-based paint removal. Sodium hydroxide is a strong alkali and is corrosive to tissues with which it comes into direct contact. Sanding or scraping surfaces which have been treated with caustic paint strippers may produce airborne alkaline dusts containing sodium hydroxide. Effects of overexposure to dusts and mists containing sodium hydroxide range from mild irritation to severe burns with scarring, depending on the severity of exposure. Direct eye contact with sodium hydroxide can result in serious injury or blindness.

The ACGIH TLV, OSHA PEL, and NIOSH REL are 2 mg/m$^3$ for airborne sodium hydroxide; all are ceiling exposure limits which should not be exceeded during periods of peak exposure.

Volatile organic compounds

Under normal circumstances, traces of many VOCs can be measured in indoor air in residences and offices, due to the widespread use of carpeting, plywood and fiberboard, synthetic fabrics, adhesives, insulation materials, cleaning products, waxes, paints, perfumes, tobacco smoke and combustion products. VOCs may be emitted in varying concentrations when latex and oil-based paint films are heated, as in heat-gun removal technique.

The concentrations of VOCs indoors in offices and residences are typically several orders of magnitude below the corresponding occupational health criteria for individual compounds, but they usually exceed outdoor levels, even in industrialized areas.[34] However, the occupational health criteria for individual compounds do not take into account the potential synergistic effects of exposure to many VOCs simultaneously.

## VI. RESULTS AND DISCUSSION

The results presented here should be interpreted with caution for several reasons. The HUD Demonstration (FHA Demonstration) was administered by the HUD Office of Policy Development and Research and a principal HUD contractor (Dewberry & Davis); exposure magnitude and variability may not be representative of locally administered public projects (i.e., by Public Housing Authorities), or of unregulated work by private contractors. Further, the housing units abated were vacant single-family homes owned by HUD as a result of FHA foreclosures; they were not a representative sample of U.S. housing. Statistical analyses on data collected by HUD contractors presented here are valid only for the population of housing units and contractors sampled. Some important variables of interest (e.g., whether work sampled was interior or exterior) were excluded due to a high percentage of missing observations. NIOSH did not attempt to verify the accuracy or representativeness of environmental sampling by HUD contractors. It should be noted that both NIOSH and HUD air samples for the various abatement methods were generally collected during work periods of less than 8-hour duration. The reported results are expressed as TWAs for the sampling periods; not 8-hr TWA exposures. In comparing results to evaluation criteria for lead, which refer to 8- to

10-hour TWA exposures, it was assumed that sampling periods for each method were representative of full shift exposures.

**NIOSH Air Sampling**

The results of air sampling for lead by NIOSH during the heat-gun method are presented in Table 1. Thirteen PBZ and six area samples were collected during work periods of 97-420 minutes at houses in Denver and Indianapolis. Airborne lead concentrations measured inside the houses ranged from not detected (ND) to 286 $\mu g/m^3$ and ND to 116 $\mu g/m^3$, for PBZ and area samples, respectively. Six of the ten inside PBZ concentrations exceeded the OSHA PEL of 50 $\mu g/m^3$. Outside the houses, three PBZ lead exposures measured during the heat gun technique were well below the OSHA PEL (range ND-3.3 $\mu g/m^3$).

The 700°F restriction for heat gun nozzle air-stream temperatures appeared to limit the effectiveness of the guns for removing paint. To compensate for the air-stream temperature limitation, workers often held the gun nozzles close to the surfaces (less than one inch), which reduced the surface area heated; thereby potentially increasing the time required for paint removal and prolonging exposure potential. Air samples for lead and VOCs, and heat gun temperature measurements were collected inside a well-ventilated (all doors and windows open) Indianapolis house for two workers performing the heat gun method. The workers used 1550 and 1440 watt variable temperature heat guns (Steinel® Model HL 1600E and Model 381) on current provided by a portable 21-amp alternating current generator (Honda® Model EL5000). One worker used two heat guns taped together to increase the effective heating area. Temperature ranges measured in the air-stream at the gun were dependent on the gun temperature setting, from 450-615°F (low setting) to 900-1042°F (high setting). At a given setting, gun temperature varied over a range of several hundred degrees fahrenheit within minutes (possibly due to cycling of heating elements or circuit power variation). Seven PBZ and four area samples for both lead and VOCs were collected during work periods of 20-171 minutes.

Results of the NIOSH measurements of lead concentrations with heat gun temperatures are presented in Table 2 and Figure 2. Lead concentration ranges measured were 27-262 $\mu g/m^3$ (PBZ samples) and 17-58 $\mu g/m^3$ (area samples); five of the seven PBZ samples exceeded the OSHA PEL of 50 $\mu g/m^3$. In four PBZ samples collected for the single heat gun , no correlation was found between mid-point of gun temperature ranges measured and lead concentration ($r^2=0.264$, $p=0.49$)--see Figure 2. However, due to the small sample size and the imprecision of heat gun temperature measurements, this result is inconclusive. No VOCs were detected in any of these samples (less than 1 $\mu g$/sample).

Eleven PBZ and two area air samples were collected for VOCs during the heat gun method in interior and exterior locations at Indianapolis houses. The results for samples with detectable VOC levels (two area, and nine PBZ) are shown in Table 3. Several VOCs were detected in low concentrations, the compounds (and concentration ranges, expressed as $mg/m^3$) detected were: ethyl acetate (ND-0.47), *n*-butanol (ND-0.25), toluene (ND-0.05), xylene isomers (ND-0.04), butyl ether (ND-0.14), total hydrocarbons (ND-3.91), octamethylcyclotetrasiloxane (ND-0.04), and decamethylcyclopentasiloxane (ND-0.07). In two of the interior PBZ samples, no VOCs were detected. All of the VOC concentrations measured were well below the applicable NIOSH RELs for occupational exposure to individual compounds; the respective RELs range from 50 to 1400 $mg/m^3$ (see Table 3). However, at the time of sampling several workers reported symptoms of respiratory irritation, which may be associated with these exposures.

Four air samples were collected in Denver during the heat gun method for VOCs. The samples were qualitatively analyzed by GC/MS; the major compounds detected were 2-methylpentane, 3-methylpentane, toluene, pinene, methyldicyclopentante, *n*-hexane, and cyclohexane. Minor compounds detected were benzene, *n*-octane, xylene isomers, *n*-nonane, and aliphatic and aromatic hydrocarbons ranging from $C_8$ to $C_{12}$. Additionally, two samples were collected during the heat gun method to qualitatively measure particulate phthalate compounds. Two phthalate compounds were detected--bis(2-ethylhexyl)phthalate and possibly, butyl (2-ethylhexyl) phthalate.

Results of air sampling for lead by NIOSH during the initial set-up method are presented in Table 4. Four PBZ and seven area samples were collected in Baltimore and Denver during work periods of 74-254 minutes. Airborne lead exposure ranges were 0.5-10 $\mu g/m^3$ and ND-36 $\mu g/m^3$ for PBZ and area samples, respectively. None of the four personal exposures exceeded the OSHA PEL of 50 $\mu g/m^3$. One short-term PBZ air sample for VOCs was collected during initial set-up in Denver; results are presented in Table 3. The sample was collected while a worker joined 6-mil plastic sheets with solvent-based adhesive. Compounds (and concentrations) detected were: *n*-hexane (26.8 $mg/m^3$), and total hexanes (45.4 $mg/m^3$). The short-term concentration of total hexanes was well below the NIOSH REL-TWA of 350 $mg/m^3$.

Results of air sampling for lead by NIOSH during chemical removal (with caustic stripper) are presented in Table 5. Five PBZ and four area air samples were collected during work periods of 55-176 minutes in Indianapolis. Airborne lead exposure ranges were 0.7-4.0 $\mu g/m^3$ (PBZ samples) and 0.3-1.0 $\mu g/m^3$ (area samples). None of the five personal exposures exceeded the OSHA PEL of 50 $\mu g/m^3$. Additionally, air sampling for alkaline dusts during the chemical removal method was conducted in Indianapolis and Denver; results for the one area and four PBZ samples are presented in Table 6. The TWA concentration of alkaline dusts (as sodium hydroxide) ranged from ND-0.34 $mg/m^3$, during work periods of 168-176 minutes. None of the four PBZ exposures exceeded the NIOSH REL-Ceiling for sodium hydroxide of 2 $mg/m^3$.

Results for three PBZ air samples collected by NIOSH for lead during the encapsulation method are presented in Table 7. TWA lead concentrations measured ranged from 1 (quantity less than the LOQ)-11 $\mu g/m^3$, during work periods of 88-376 minutes. None of the three personal exposures exceeded the OSHA PEL of 50 $\mu g/m^3$.

Results for three PBZ and two area samples collected for airborne lead by NIOSH during the replacement method are presented in Table 8. The TWA lead concentrations ranged from 0.6-10 (<LOQ) $\mu g/m^3$, during work periods of 70-121 minutes.

During December 1989, HUD contractors in Indianapolis used portable propane heaters inside contained housing units; i.e., to contain lead dust all of the windows and doors had been sealed with 6-mil plastic. Short-term air sampling was conducted with detector tubes for $CO_2$ and CO. The results are presented in Table 9. Ambient outdoor concentrations measured were 225-300 ppm $CO_2$ and no detected CO. Inside two sealed houses where propane heaters had been in use for short periods (1-2 hours) $CO_2$ and CO concentrations were significantly elevated: ranges were 1,800 - >3,000 ppm, and ND - 30 ppm, respectively. The contractors were immediately notified that the use of the heaters without adequate ventilation represented a health hazard. Subsequently, in the same houses with propane heaters on and additional ventilation provided (open windows or a negative air unit), the $CO_2$ and CO levels were reduced to 400-600 ppm and ND-10 ppm, respectively. $CO_2$ measurements were also made in sealed (and unheated) houses with no propane heater in use. The results were 700-825 ppm $CO_2$ (room with four workers performing chemical removal) and 800 ppm $CO_2$ (room with three workers using heat guns). The short-term measurements of $CO_2$ in unheated houses were within the ASHRAE guidelines for acceptable indoor air quality; however, insufficient measurements were made to adequately assess the ventilation. All of the $CO_2$ and CO exposures measured were below the respective NIOSH REL-TWAs of 5000 ppm and 35 ppm.

**NIOSH Bulk and Surface Sampling**

Two bulk samples of lead-based paint were collected at a house in Denver, and subsequently heated in a laboratory oven to a temperature of 370°C (700 °F) to simulate surface temperatures during the heat gun method. During heating, the oven air was sampled for VOCs and phthalates; the resulting samples were qualitatively analyzed by GC/MS. Compounds which evolved from the two heated paint samples were similar. Hundreds of compounds were detected on the gas chromatograms generated from these samples, and it was not feasible to identify every component. Generally, most of the compounds identified were oxygenated hydrocarbons such as aldehydes, ketones, alcohols, acetates, acrylates, and methacrylates. Major components identified included benzene, isobutanol, butane, acetone, methyl pentane, haptene, isobutyl acetate, butyl methacrylate, acetaldehyde, propanol, hexanal, octanal, and bis(2-ethylhexyl) phthalate. Several saturated and unsaturated aliphatic hydrocarbons, and acetic acid were also detected.

Bulk and surface dust sampling were conducted at a Baltimore house on the first day of abatement activities. The house was brick, with painted walls and wood trim on the interior, and exterior (wood) front porch columns and roof. Based on previous XRF and AAS measurements the interior wood trim and exterior front porch trim had been scheduled for lead abatement. Paint and soil sampling results are presented in Tables 10. Lead concentrations measured (by AAS) in paint chip samples from three interior surfaces and one exterior (porch) surface ranged from 0.11 to 2.1%. Under HUD regulations, painted surfaces with lead concentrations at or above 1.0 milligram per square centimeter ($mg/cm^2$) or 0.5% by weight must be abated by Public Housing Authorities. Soil lead concentrations in three samples collected in the front yard ranged from 75-220 ppm; below the current Environmental Protection Agency (EPA) guideline of 500-1000 ppm.

The contractor had designated the front porch of this house as a "clean" area for staging abatement work, although it was visibly contaminated with dust and paint chips. A two-stage structure constructed of plastic sheeting on a wood frame was located on the porch and attached to the front door frame; it was used for worker entry/egress and decontamination. NIOSH investigators collected five surface dust samples on the front porch in the "clean" zone, and four surface samples inside the decontamination structure on both the "dirty" and "clean" sides. The results of surface dust sampling are presented in Table 11. Lead concentrations on the porch ("clean" zone) ranged from 480-990 $\mu g/ft^2$ on the balustrade and 4,200-13,000 $\mu g/ft^2$ on the floor. After collecting the initial five samples, we requested that the contractor briefly clean these areas

Post-vacuuming samples were collected from areas immediately adjacent to the original samples; lead concentrations were reduced to 150-250 $\mu g/ft^2$ (balustrade) and 990-1300 $\mu g/ft^2$ (floor). Four surface dust samples were collected from the plastic walls and floors inside the decontamination structure. The lead concentrations measured on the floors were 1800 $\mu g/ft^2$ on the designated "clean" side and 460 $\mu g/ft^2$ on the "dirty" side. Lead concentrations measured on the walls were 12 $\mu g/ft^2$ (value less than the LOQ) on the "clean" side and 460 $\mu g/ft^2$ on the "dirty" side. The HUD Guidelines have adopted clearance criteria for abated residences of 200 $\mu g/ft^2$ for floors, 500 $\mu g/ft^2$ for walls, and 800 $\mu g/ft^2$ for window wells. The visual contamination, and surface dust measurements indicate that the porch should not have been designated as a "clean" area by the contractor. A brief cleaning with a HEPA vacuum reduced the surface lead concentrations, but further cleaning would have been required for all of the surfaces to meet HUD clearance criteria.

Friable duct insulation suspected as asbestos-containing material (ACM) was observed in two Indianapolis housing units undergoing abatement (no labels or warning signs were present). Representative bulk samples of three insulation materials were collected in two houses; subsequent laboratory analysis confirmed that all were comprised of 10-25% chrysotile asbestos. In the units sampled, the ACM was located in unoccupied areas (basements) where no abatement work was scheduled. However, asbestos was used in household building materials prior to 1978; the potential for disturbance of ACM during lead abatement should have been evaluated for each housing unit prior to abatement.

**NIOSH Observations**

During site visits NIOSH investigators observed problems and inconsistencies with respect to worker protection. Contractors at the sites were notified, and these have been presented to HUD in previous reports for this HHE, which contained interim recommendations. The most significant are presented below, to illustrate important considerations in planning health and safety aspects of residential lead abatement work.

1. The requirement for all workers to use respiratory protection for all abatement activities was not consistently applied and was not based on the degree of hazard. For example, workers laying plastic sheeting around the exterior of houses during initial set up exposed to ambient outdoor air were required to wear air-purifying respirators, while supervisors and observers a few feet away were not. The respiratory protection requirement may have created an

economic disincentive for contractors to reduce exposures through preferred means (e.g., engineering controls and good work practices).

2. Attention to engineering controls and proper method-specific work practices to control occupational exposures was not adequate during initial worker training, or during abatement work, given that these are preferred by NIOSH and OSHA to respiratory protection and other personal protective equipment.

3. Facilities and procedures for preventing worker exposure to lead through ingestion, and carry-home of lead contamination were inadequate. For example, running water, or clean changing and storage areas were typically unavailable. In at least one case, the designated "clean" area (used for clothes changing, eating and smoking) was located in an area which was visibly contaminated with paint chips and dust. Also, workers were observed to convey lead-contaminated garments home in personal vehicles.

4. Adequate personal protective equipment was not consistently used. Workers performed chemical removal (caustic paste) without eye protection or chemically resistant protective clothing; resulting in contamination of skin and personal clothing. Chemical burns of the skin due to contact with caustic were observed.

5. Potential exposure of lead abatement workers to ACM was not addressed in the protocol for the Demonstration or in the initial assessment of housing units. No effort was made to identify friable ACM in housing units undergoing abatement.

6. Electrical safety and fire hazards were observed at several locations; resulting in large part from the lack of utilities at housing units abated. These included use of portable heaters in work areas contained in 6-mil plastic, frequently overloaded portable generator electrical circuits, and improper grounding of power tools.

7. Slip, trip and fall hazards were common due to frequent work on ladders, multiple extension cords of 100-300 ft length, the extensive use of 6-mil plastic on floors and steps, and (in some cases) poorly constructed scaffolding; in conjunction with use of disposable booties which greatly reduced floor-to-sole friction.

**Analysis HUD Data-Environmental**

Environmental monitoring data collected by HUD contractors which was provided to NIOSH to support this evaluation included; PBZ and area air sampling results, lead paint concentrations, paint condition (rated on numerical scale), pre- and post-abatement soil lead concentrations, square feet abated, and contractor identification. The results for PBZ and area air sampling and other environmental monitoring were linked by unit number and contractor name.

ANALYSIS 1

This purpose of this ANOVA was to determine important independent variables associated with observed variation in airborne lead concentrations (by sample). The airborne lead concentrations reported (including area and PBZ results) were used as the dependent variable, while the corresponding abatement method, contractor, housing unit, and sample volumes were initially selected as independent variables. The housing unit variable was nested under contractor because each housing unit had only one contractor.

The spreadsheet file provided to NIOSH contained data which had been collected by HUD contractors during abatement activities, and included 2635 area and PBZ air sample results. Twenty-two categories were used in the original file to describe the abatement method. To simplify the analysis, NIOSH reclassified these into 11 categories; presented in Appendix A. No method information was provided for 208 (7.9%) of the results (the abatement strategy was provided). Due to the significant number of samples involved, and other information which could be obtained from them, these were included in the analysis under "missing" method category. Twenty four samples provided without contractor or unit number information were deleted, leaving 2611 air sample results representing 12 contractors and 163 housing units.

A preliminary analysis of the results was performed to check if sample volume was independently associated with airborne lead levels (it could be if short sampling times were consistently used during periods of high or low exposure). The mean sample volume for area and PBZ samples was 413 liters (range: 0 (sic) - 1634 liters). Sampling times and flow rates were not provided to NIOSH (reportedly a sampling flow rate of 2 $\ell$/min was generally used). No correlation between sample volume and airborne lead concentration was found (Pearson coefficient $r^2$=0.003). As a result, sample volume was not included as a variable of interest.

The relative frequency distribution for lead concentrations in all the results provided (2635 samples) is presented in Figure 3. Lead concentrations were generally low; 95% of all air samples collected by HUD contractors were at or below the OSHA PEL of 50 $\mu g/m^3$. Air sampling results for 1402 PBZ samples and 1233 area samples are presented in Tables 12 and 13, respectively; stratified by NIOSH-assigned method category. The overall geometric means for PBZ and area samples were 3.1 $\mu g/m^3$ and 2.0 $\mu g/m^3$, respectively. Geometric means for the 11 NIOSH method categories were 1.4-7.6 $\mu g/m^3$ for PBZ samples, and 1.0-4.3 $\mu g/m^3$ for area samples. Variability within method categories was high; the geometric standard deviations were 1.9-7.6. For all of the methods, the minimum airborne lead concentration reported was at or near the laboratory-assigned LOQ (0.4 $\mu g/m^3$).

Fifth, 10th, 50th, 95th and 99th percentiles for PBZ exposures reported, classified by method category, are presented in Table 14 and graphically (50-99th percentiles only) in Figure 4. The 95th percentile PBZ exposures were below the OSHA PEL-TWA of 50 $\mu g/m^3$ for all methods (range: 9-48 $\mu g/m^3$) except abrasive, heat-gun and "other" methods (range: 58-207 $\mu g/m^3$). The maximum PBZ exposures reported for precleaning, final cleaning, and encapsulation methods were below the OSHA PEL (range 11-36 $\mu g/m^3$).

The ANOVA (including 2611 samples) indicated a significant interaction between method and contractor; to best model variation in air sampling results an interaction term was included. The resulting ANOVA was significant overall ($p=0.0001$), as was the interaction term ($p=0.0001$). Housing unit (nested under contractor) was also significant ($p=0.0001$). The mean airborne lead concentrations for combinations of method and contractor are reported in Table 15 and in Figure 5. A given contractor may have been "low" on one method and "high" on another, with respect to mean airborne lead. The interaction must be interpreted with caution, since there were many missing combinations of method and contractor. The largest range of mean airborne lead concentrations by contractor, 0.5 $\mu g/m^3$ - 310 $\mu g/m^3$, was observed in the "other" method category; the smallest range, 1.4 $\mu g/m^3$ - 6.0 $\mu g/m^3$ in the encapsulation method. Variation in the "other" category was expected due to the incorporation of miscellaneous activities, the original designations were: "caulk, decon, demo, monitor, neg air, repair, sawing, and waste."

The interaction between contractor and method necessitated simpler analyses of the data. As follow-up, separate ANOVAs were performed for each NIOSH-assigned method category (see Table 15). For these analyses airborne lead concentration was the dependent variable; contractor and housing unit (nested under contractor) were the independent variables. Contractor was a significant variable for abrasive, encapsulation, final cleaning, heat gun, replacement, set up, and "other" methods (range for p-values: 0.0001-0.02). Housing unit (nested under contractor) was a significant variable ($p<0.05$) for abrasive, chemical removal, cleaning, heat gun, replacement, set up, and "other" methods.

ANALYSIS 2

This purpose of this analysis was to determine important independent variables for the variance in observed mean airborne lead concentrations by housing unit. The log of unit-specific mean airborne lead concentration (area and PBZ) was used as the dependent variable, while the corresponding mean pre-abatement soil lead concentration, mean paint lead concentration, median substrate condition, total square feet abated, contractor, city, and abatement strategy were selected as independent variables. The abatement strategy for each unit was assigned by HUD; it specified a first (and if that was not feasible), second, third, and fourth choices for abatement method to be used within the unit. Data representing 191 housing units with at least one variable of interest were reported to NIOSH. For this analysis we deleted units missing information for one or more of the eight variables of interest, resulting in 128 units with non-missing observations on all variables; representing 12 contractors and six cities. The number of observations, minimum, maximum, mean (arithmetic) and standard deviation for these variables overall is presented in Table 16. The analysis was an analysis of covariance (ANCOVA), due to the mixture of categorical (contractor, city, strategy, and median paint condition) and continuous (mean pre-abatement soil lead, mean paint lead, and total square feet abated) variables.

The overall model (with all independent variables) was significant ($p=0.0001$). The significant variables (and corresponding Type III p-values) were: strategy ($p=0.0001$), mean pre-abatement soil lead concentration ($p=0.0005$), and mean paint lead concentration ($p=0.0003$). Insignificant ($p>0.05$) variables were: total square feet abated, contractor, city, and median paint condition. Table 17 presents the descriptive statistics for unit mean airborne lead concentration (the dependent variable) vs. unit abatement strategy. A least squares means analysis (with Bonferroni adjustment) was performed to compare strategies. The heat gun strategy was associated with significantly higher unit mean airborne lead concentrations (mean: 22 $\mu g/m^3$) than all of the other strategies (range of means: 5.0-12 $\mu g/m^3$).

Results for the abrasive strategy (mean 8.9 $\mu g/m^3$) are deceptively low, because in most units assigned this strategy, abrasive abatement methods (the assigned first choice) were not actually used due to their ineffectiveness. To illustrate; 14.8% of housing units sampled were assigned to the abrasive strategy; if abrasive methods were actually used the proportion of air sampling results should be a similar percentage. In fact, abrasive methods represented only 1.9% of the air sample results. Under the HUD protocol, the second and third choice methods assigned to the abrasive strategy (which were often used) were chemical removal and enclosure, respectively. Unlike abrasive methods, these methods were generally associated with low exposures.

None of the other abatement strategies differed significantly with respect to unit mean airborne lead, including heat gun and replacement methods performed with mechanical general ventilation ("negative air") provided. However, it is important to recognize the potential effectiveness of general ventilation was not adequately addressed in the Demonstration protocol: there were no specifications for location and volume of ventilation to be provided, and no ventilation measurements were made to assess its effectiveness.

As a follow-up to the ANCOVA, a correlation analysis of mean paint lead concentration vs. mean airborne lead concentration was performed--see Figure 6. A very weak ($r^2$ = 0.175), but statistically significant ($p < 0.01$) correlation was observed. This result is consistent with the significant dependence of airborne lead concentrations on a number of variables in addition to paint lead concentration.

ANALYSIS 3

This purpose of this analysis was to determine important independent variables for the observed variation in mean change in soil lead concentrations by housing unit. The dependent variable, mean change in soil lead concentration, was calculated from results provided as the mean post-abatement minus the mean pre-abatement. The corresponding city, contractor, total exterior square feet abated, mean paint lead concentration, abatement strategy and median paint condition were selected as independent variables.

Data representing 164 housing units with either pre- or post-abatement soil lead results were provided to NIOSH for analysis; 130 units with at least one of each were included in this analysis. The soil sampling protocol required composite samples to be collected along four walls of the residence. During collection of the soil samples, the street-facing wall of each unit reportedly had been consistently designated wall 1, and the other walls numbered in clockwise rotation. Among the

130 units included in our analysis, sampling results were reported for a total of 455 walls (mean 3.5 walls/unit).

Preliminary ANOVAs were performed to analyze soil lead concentrations by wall and unit. Pre-abatement soil results differed significantly both by wall and unit (p-values 0.0001 and 0.0035 respectively). We did not attempt to determine potential causes for the observed differences between walls prior to abatement. Mean pre-abatement soil lead concentrations were 657 ppm (wall 1), 876 ppm (wall 2), 666 ppm (wall 3), and 903 ppm (wall 4). However, the mean change in soil lead concentration (post minus pre) did not differ significantly by wall or unit ($p=0.59$).

The distributions of mean pre- and post-abatement soil lead concentrations are presented in Figure 7. Mean soil lead concentrations for 15 units (12%) pre-abatement and 21 units (16%) post-abatement exceeded the EPA recommended range of 500-1000 ppm for soil lead. Overall the mean change in soil lead concentration was 115 ppm, with a range of -1111 ppm to 1640 ppm (standard deviation 331 ppm). The distribution of results for mean change in soil lead concentration is shown in Figure 8. The mean change in soil lead was an increase for 96 units (74%) and a decrease for 34 units (26%). However, only 9 (7%) had mean changes in soil lead significantly ($p<0.05$) different than zero; 8 (6%) were increases (range 44-470 ppm) and 1 was a decrease (-201 ppm). The lack of significance for most units may have resulted from the high intraunit variability of composite soil sample results and limited number of samples per unit (mean 3.5 paired samples/unit).

The overall model was an analysis of covariance (ANCOVA), due to the mixture of continuous (total exterior square feet abated, mean paint lead concentration) and categorical (city, contractor, strategy, median paint condition) variables. The overall model was not significant ($p = 0.12$). Additionally, even when they were considered individually, there were no significant differences in mean change in soil lead concentration among any of the variables. The insignificance of the model may be at least partially due to random error or variation inherent in the collection and analysis of composite soil samples.

A followup analysis of (log) mean airborne lead vs. mean change in soil lead concentration in 128 units with non-missing values found no significant correlation ($r^2=0.016$, $p>0.05$). The correlation plot is presented in Figure 9.

**Analysis of HUD Data-Medical**

Results of blood lead levels (BLLs) collected between October 1989 and September 1990, were analyzed. Initial pre-abatement blood leads were performed on 287 workers. Two workers had initial BLL results >25 µg/dl (38 µg/dl and 39 µg/dl); these workers were excluded from work on the demonstration project.

Compliance with the protocol for followup BLL testing was incomplete: 190 workers (66.7%) had no followup BLL reported. Only 95 workers (33.3%) had one or more followup BLL tests reported during the demonstration project; 32 workers (11.2%) had two followup BLLs, ten workers (3.5%) had three followup BLLs, and one worker (0.4%) had a fourth followup BLL recorded. This failure of blood lead surveillance was perhaps at least partially due to changing job sites, weather-related delays, multiple contractors, and relatively high employee turnover. In many cases, however, the required medical monitoring protocol simply was not adequately followed by abatement contractors.

Of the 95 workers with one or more followup BLL test results, 29 (31%) had an increase in BLL of 5 or more µg/dl (mean 8, maximum 22 µg/dl). Blood leads decreased by five or more µg/dl in 17 (18%) of workers with more than one recorded BLL (mean 10, maximum 17 µg/dl).

One worker's followup BLL result exceeded 25 µg/dl during the demonstration project. Though this individual entered the project with a BLL of 5 µg/dl on November 1, 1989, and his level was undetectable (less than 5 µg/dl) during a second blood draw on April 23, 1990, his BLL had increased to 27 µg/dl on his exit from the project on September 27, 1990. Further information on this or other individual workers' habits, assignments (other than city and contractor) and tasks was not provided to NIOSH.

## VII. CONCLUSIONS

**NIOSH Environmental Monitoring**

Most of the exposures measured during the heat gun method exceeded the OSHA PEL of 50 $\mu g/m^3$, except for exterior heat gun work, for which exposures were well below the PEL. Sampling of the airspace above heated paint chips in the laboratory indicated that a large number of VOCs may be emitted during the heat gun method. Personal exposures to VOCs measured at housing units during interior and exterior heat gun paint removal ranged from none detected to quantifiable concentrations well below the applicable exposure criteria for individual compounds. However, workers reported respiratory irritation associated with some of the interior exposures.

The heat gun method resulted in the highest personal exposures to lead, although HUD restricted the airstream temperature at the gun nozzle to 700°F. A previous study of lead-based paint removal with heat guns concluded that the resulting level of airborne lead depends on many variables including the time required for removal.[35] The heat gun method is dependent on heating surfaces until the paint film softens and delaminates from the substrate, at times allowing removal with relatively little scraping. NIOSH investigators observed that the restriction appeared to reduce the guns' effective heating area and thereby may have actually increased airborne lead exposures by increasing the time, and/or intensity of, manual scraping required for paint removal. No correlation between heat gun airstream temperature and personal airborne lead exposures were measured for a single heat gun in a well-ventilated house (all doors and windows open), although the results were insufficient to be conclusive.

Airborne exposures to lead measured during other abatement methods were relatively low. It is important to note that NIOSH sampling did not include all of the methods (e.g., abrasive) that were used in the Demonstration. Additionally, the limited number of samples collected for each method precludes estimation of the maximum-risk exposures for each method (this was addressed by HUD air sampling-see below). Air sampling for lead indicated that personal exposures during set up, chemical removal, encapsulation, and replacement methods were well below the OSHA PEL of 50 $\mu g/m^3$. Exposures to alkaline dusts (as sodium hydroxide) were below the NIOSH REL-Ceiling limit.

In houses sealed with plastic for containment of lead dust, the use of propane heaters without adequate ventilation for short periods (1-2 hours) at the beginning of workshifts resulted in significantly elevated exposures to $CO_2$ and CO, although below the respective NIOSH RELs. The contractors discontinued the practice immediately (as recommended by NIOSH); it is likely that otherwise use of the heaters would have resulted in hazardous concentrations of $CO_2$, CO and other combustion products during the workshift. Short-term measurements of $CO_2$ in similarly sealed houses without propane heaters were within the criteria recommended by ASHRAE for acceptable indoor air quality. However, more measurements would be required to adequately assess the ventilation. Workers joining 6-mil plastic sheeting with solvent-based adhesive during the set up method were exposed to hexanes, however the exposures were well below the respective NIOSH RELs.

Surface dust sampling at a house undergoing abatement in Baltimore indicated that the front porch area designated and utilized as a "clean" staging area by the contractor was in fact heavily contaminated with lead. Due to its location in a contaminated area, the two-stage structure erected at the front door of the house did not prevent contamination of the worker's equipment, clothing, and food with lead.

Analysis of three bulk samples of duct insulation in two Indianapolis houses revealed that the materials were ACM. Although the ACM in these houses was not in occupied areas scheduled for abatement, the potential for worker exposure to asbestos from disturbance of household materials was not adequately addressed in the Demonstration protocol.

**HUD Environmental Data**

Analysis of 2611 air sampling results indicated that personal exposures to airborne lead measured were generally low (geometric mean 3.1 $\mu g/m^3$), but the variability of exposures was very high (geometric standard deviation 4.4, maximum 916 $\mu g/m^3$). While some of the variation observed may be due to sampling inconsistencies, analysis of the results suggested that the abatement method, housing unit abated, and the contractor were important determinants of airborne lead exposure.

Area and PBZ airborne lead concentrations varied significantly between method categories, contractors (with significant method-contractor interaction), and housing units. Significant variation between contractors was observed for abrasive, encapsulation, final cleaning, heat gun, replacement, set up, and "other" methods; and between housing units (nested under contractor, as each unit was abated by a single contractor) for abrasive, chemical removal, cleaning, heat gun, replacement, set up, and "other" methods. The observed variations between contractors, and the method-contractor interaction are consistent with work practices as an important determinant of lead exposures.

The mean airborne lead concentration by housing unit varied significantly with the abatement strategy, the mean pre-abatement soil lead concentration, and the mean paint lead concentration for the housing unit. Other variables (total square feet abated, contractor, city, or median paint condition) were not significant. Paint lead concentration alone is a poor predictor of potential worker exposures during abatement; only a very weak correlation was found between mean paint concentrations and mean airborne lead concentrations in abated housing units.

Personal exposures to airborne lead potentially exceeding the OSHA PEL of 50 $\mu g/m^3$ were measured during eight of eleven NIOSH-assigned method categories; abrasive, chemical removal, cleaning, enclosure, heat gun, "other," replacement, and set up. To compare results to the OSHA PEL, it was necessary to assume that less-than full shift sampling periods were representative of full shift exposures.

Less than 5% of the personal exposures to lead measured for chemical removal, cleaning, enclosure, replacement, and set up methods; and none of the exposures for encapsulation, final cleaning, and precleaning methods exceeded 50 $\mu g/m^3$.

All workers were required to wear at least half-mask air-purifying respirators with HEPA-filter cartridges during the demonstration for any method. Maximum personal exposures measured were within the protection factor offered by these respirators, with the exception of a few (<1%) heat gun exposures. Additional emphasis on worker training, medical monitoring, and good work practices may eliminate the need for mandatory respiratory protection during some of the abatement jobs.

Results suggest that the containment procedures used in the Demonstration were not completely successful. Pre- and post-abatement composite soil sampling for abated housing units indicated that abatement in some cases resulted in increases in soil lead levels one to three feet from the exterior walls. The mean soil lead concentrations increased in 74% of the 130 units reported; however, only 8 (6%) of the unit increases reached statistical significance (95% confidence), and some of these may have been due to random chance. The mean change in soil lead concentration by housing unit did not vary significantly with city, contractor, total exterior square feet abated, mean paint lead concentration, abatement strategy and median paint condition. The insignificance of analyses of soil sampling results may be at least partially due to random error or variation inherent in the collection and analysis of composite soil samples, and the relatively small number of paired composite samples collected per unit (mean 3.5).

It is likely that the measured increases in soil lead contamination were due to non-airborne lead contamination that fell directly, or was carried from, the substrate abated. Results suggest that the observed changes in soil contamination measured were not due primarily to fugitive airborne emissions during interior or exterior abatement work. Area airborne lead concentrations (interior and exterior) were generally low, with a geometric mean of 2 $\mu g/m^3$. No correlation ($r^2$=0.016) between mean airborne lead and mean change in soil lead concentration was observed in 128 units with non-missing values.

**HUD Medical Data**

The demonstration project protocols for worker protection and for medical monitoring were generally more protective than the OSHA lead standard for general industry (29 CFR 1910.1025). Given that abatement is a public health activity, this is appropriate.

The results of the monitoring did not generally indicate worrisome increases in BLL levels, although the lack of adequate followup precludes definitive conclusions. The single followup BLL exceeding 25 $\mu g/dl$ demonstrates the potential of lead abatement work for excessive exposures and underscores the need for continued routine BLL monitoring.

The low rate of followup of medical monitoring by HUD contractors in the demonstration (33.3%) was not acceptable. A higher rate of followup is essential for any meaningful evaluation and surveillance of abatement workers. We are thus unable to determine how many workers may have suffered unrecognized increases in BLL. On the other hand, a variety of problems may cause difficulties in medical monitoring of lead abatement workers. A large number of those who were lost to follow-up may have simply left the project with minimal exposure after a brief period of time. Accounting for the cases of early attrition may have allowed a more definitive interpretation of the results.

It is helpful to consider medical monitoring as an example of epidemiologic surveillance. Epidemiologic surveillance is defined by the Centers for Disease Control as:

> "the ongoing and systematic collection, analysis, and interpretation of health data in the process of describing and monitoring a health event. This information is used for planning, implementing, and evaluating public health interventions and programs. Surveillance data are used both to determine the need for public health action and to assess the effectiveness of programs."[36]

The medical monitoring required by HUD, if enhanced and continued, has the potential to minimize worker exposures to lead by: 1) identifying and controlling high risk operations; 2) targeting interventions to prevent individual workers from exceeding acceptable BLLs; and, 3) over time, evaluating the effectiveness of the overall program.

## VIII. RECOMMENDATIONS

The following recommendations should be applied to future lead abatement by HUD (or private contractors) in public housing. They are offered to minimize worker exposures to lead, and increase effective medical monitoring and surveillance. Implementation of these recommendations will help achieve one of the national health objectives specified by *Heathy People 2000*, which is to eliminate exposures that result in lead concentrations greater than 25 μg/dl of whole blood. Some of these recommendations were previously provided to HUD in interim reports released in February 1990 and March 1991.

1. Lead-based paint abatement methods currently associated with the highest personal airborne exposures to lead, such as heat gun and abrasive removal, should be avoided wherever feasible.

2. HUD should continue research and development to provide method-specific engineering controls and work practices to reduce worker exposures to lead and contamination of surroundings, particularly during on-site paint removal and cleaning methods. Further study is needed to determine if the 700°F temperature restriction placed on heat guns is an effective control of airborne lead exposures during lead-based paint removal.

3. Respiratory protection may be necessary for certain operations or methods, such as paint removal by chemicals, heat gun, or abrasive techniques, and some set-up, and cleaning operations. However, respirators are the least preferred method of controlling airborne lead exposure, and **they should not be used as the only means of preventing or minimizing exposures. Respiratory protection requirements are not an acceptable substitute for adequate training, supervision, appropriate engineering controls, and environmental or medical monitoring.** Initial respiratory protection requirements for abatement work (which may be based on conservative assumptions) should be modified with appropriate job-specific requirements based on air monitoring results. Respirator selection for each job category at every worksite should be determined by an industrial hygienist or other qualified individual, based on maximum airborne exposures measured.

4. Facilities for worker personal hygiene should be improved to minimize workers' exposure to lead through ingestion, and carry-home of lead contamination. Adequate washing facilities including running hot and cold water and wherever feasible, showers, should be provided at the worksite so that workers can remove lead particles from skin and hair. Contractors should arrange for collection and disposal of the wastewater in accordance with local and state requirements. Wherever feasible, contractors should supply a portable trailer to contain storage, washing facilities, and clean areas.

5. All workers exposed to lead should wash their hands and faces before eating, drinking, or smoking, and they should not eat, drink, or use tobacco products in the work area, or other potentially contaminated areas on site. Tobacco and food products should never be permitted in the work area. Contaminated work clothes should be removed before eating.

6. Workers should change into work clothes only at the worksite. Street clothes should be stored separately from work clothes in a clean area provided by the employer so that they are not contaminated. Workers should change back into their street clothes after washing or showering and before leaving the worksite to prevent the accumulation of lead dust in the workers' cars and homes, and thereby protect family members from exposure to lead.

7. Appropriate disposable or washable work clothes should be provided by the employer. To reduce the potential for heat stress, breathable clothing should be used for all methods except for chemical removal, where chemical-resistant clothing is necessary. Worker shoes or disposable booties should have non-skid soles. Employers should arrange for the laundering of protective clothing; or, if disposable protective clothing is used, the employer should maintain an adequate supply at the worksite and arrange for its safe disposal according to applicable Federal and State regulations. The launderer of lead-contaminated clothing should be advised (in writing) of the lead contamination and of the potentially harmful effects of lead.

8. Worker and supervisor training should be modified to emphasize method-specific health hazards, and proper work practices with the goal of reducing exposures and the significant variation between contractors. Also, training should provide additional emphasis on the prevention of safety and physical hazards such as slip, trip and fall, fire (due to heat guns and portable heaters), improper use of scaffolds and ladders, and electrical equipment hazards.

9. The initial risk assessment and evaluation of housing units should include an assessment of (a) potential disturbance of, and exposure to asbestos-containing materials (ACM) during abatement; (b) appropriate location for the designated "clean" area for decontamination and other support activities; and (c) determination of whether soil lead levels adjacent to housing units exceed Federal or State guidelines. Specific procedures for control of these hazards should be developed and included in the abatement work. The designated "clean" area for abatement jobs of significant duration (>2 weeks) should be verified as clean with surface dust sampling on a predetermined schedule.

10. HUD should perform additional studies to determine appropriate interior and exterior containment procedures for each abatement strategy. Containment procedures should be based on the relative contributions of airborne lead dust and non-airborne chips and fines to lead contamination of surroundings during abatement activities. For any work within sealed or contained areas, ventilation should be provided to meet the ASHRAE recommendations for acceptable indoor air quality. No one, including inspectors or supervisors, should be allowed to enter or exit potentially contaminated areas without appropriate protective work clothing (which is left on the job) and decontamination to prevent the spread of lead paint chips and dust to surroundings.

11. Medical monitoring of workers performing lead abatement should be continued, with increased compliance. The medical monitoring requirements of the HUD Interim Guidelines should be incorporated into contracts and specifications for lead abatement work. The data for HUD-funded projects should be collected and compiled by HUD, and utilized for surveillance. Additional administrative emphasis and contractual requirements could be used to increase compliance by abatement contractors. Measures could include a "tickler" system wherein contractors and workers can be given timely reminders of overdue tests, or a more centralized system of worker certification (which could be helpful when workers switch employers or cities).

    There is too much uncertainty about both the risks attendant to various processes and the effectiveness of protective measures, to proceed without this essential surveillance. It would be ironic indeed if a program designed to provide a public health benefit to children resulted in preventable harm to adult workers.

12. Cases of significant BLL increase; or BLL exceeding 25 $\mu g/dl$ should trigger timely investigation of potential exposures, work practices, and personal

protective equipment. Industrial hygiene monitoring, for example, can be directed toward the sentinel case and workers performing similar tasks, possibly identifying previously unrecognized exposure potential. Problems in the enforcement of protective measures may be identified, thus efficiently targeting oversight efforts. This type of follow-up activity can both prevent further increases for the individual worker and, by identifying problem areas, prevent increased exposure for other workers.

The thresholds at which these investigations are triggered is a decision which can be made somewhat arbitrarily and modified as necessary. Most importantly, each of these sentinel cases should be viewed as having potential preventive implications for the entire project.

## IX. REFERENCES

1. HUD [1991]. The HUD lead-based paint abatement demonstration (FHA). Washington, DC: U.S. Department of Housing and Urban Development, Office of Policy Development and Research, August 1991.

2. ATSDR [1988]. The nature and extent of lead poisoning in children in the United States: a report to Congress. Atlanta, GA: U.S. Public Health Service, Centers for Disease Control, Agency for Toxic Substances and Disease Registry.

3. NIBS [1989]. Lead-based paint testing, abatement, clean-up and disposal guidelines. Washington, D.C.: The National Institute of Building Sciences. Document No. 5047-8.

4. HUD [1990]. Lead-based paint: interim guidelines for hazard identification and abatement in public and indian housing. Washington, DC: U.S. Department of Housing and Urban Development, Office of Public and Indian Housing, September 1990.

5. NIOSH [1984]. NIOSH manual of analytical methods, 3rd edition, vol. 1 and 2, with 1985, 1987 and 1989 supplements. Eller, P., Editor. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 84-100.

6. McKnight, M, Byrd, WE, Roberts, WE, and Lagergren, ES [1989]. Methods for measuring lead concentrations in paint films. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology. NIST Publication 89-4209.

7. CDC [1988]. NIOSH recommendations for occupational safety and health standards 1988. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. MMWR 37(suppl S-7): pp 1-29.

8. ACGIH [1991]. Threshold limit values for chemical substances and physical agents and biological exposure indices for 1991-1992. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

9. Code of Federal Regulations [1989]. OSHA Table Z-1, air contaminants-permissible exposure limits. 29 CFR, Part 1910.1000. Washington, DC: U.S. Government Printing Office, Federal Register (OSHA 3112).

10. ASHRAE [1989]. Ventilation for acceptable indoor air quality. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Standard 62-1989.

11. NIOSH [1981]. Occupational health guidelines for chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-123, and supplements 88-118, 89-104.

12. Hernberg, S, et al [1988]. Lead and its compounds. In: Occupational medicine. 2nd ed. Chicago, IL: Year Book Medical Publishers. 1988.

13. Landrigan, PJ, et al [1985]. Body lead burden: summary of epidemiological data on its relation to environmental sources and toxic effects. In: Dietary and environmental lead: human health effects. Amsterdam: Elsevier Science Publishers.

14. Proctor, NH, Hughes, JP, Fischman, ML [1988]. Lead. In: Chemical hazards of the workplace. 2nd ed. Philadelphia, PA: J.B. Lippincott Company, Philadelphia, pp 294-298.

15. World Health Organization [1980]. Recommended health-based limits in occupational exposure to heavy metals. Geneva: Technical Report Series 647.

16. Muhaffey K, Annest J, Roberts J, Murphy R [1982]. National estimates of blood lead levels. United States, 1976-1980. New Engl J Med 307:373-9.

17. Annest J, Dirkle J, Makuc C, Nesse J, Bayse D, Kovar M [1983]. Chronological trends in blood lead levels between 1976 and 1980. New Engl J Med 308:1373-7.

18. CDC [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.

19. NIOSH [1978]. Occupational exposure to inorganic lead. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 78-158.

20. Hernberg S, Dodson WN, and Zenz C [1980]. Lead and its compounds. In: Zenz C, Occupational Medicine. 2nd Ed. Chicago: Year Book Medical Publishers, pp. 547-582.

21. Landrigan PJ, Froines JR, Mahaffey KR [1980]. Body lead burden: summary of epidemiological data on its relation to environmental sources and toxic effects. Chapter 2. In Mahaffey KR (ed.): Dietary and environmental sources and toxic effects. Amsterdam: Elsevier Science Publishers.

22. Code of Federal Regulations [1989]. OSHA lead standard. 29 CFR, Part 1910.1025. Washington, DC: U.S. Government Printing Office, Federal Register.

23. ATSDR [1990]. Toxicological profile for lead. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. DHHS (ATSDR) Publication No. TP-88/17.

24. DHHS [1990]. Healthy people 2000: national health promotion and disease objectives. Washington, DC: U.S. Department of Health and Human Services, Public Health Service, DHHS Publication No. (PHS) 91-50212.

25. OSHA, and NIOSH [1991]. Working with lead in the construction industry. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, and U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health. OSHA Publication No. 3126.

26. NIOSH [1991]. NIOSH alert-request for assistance in preventing lead poisoning in construction workers. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 91-116.

27. ATSDR [1990]. Toxicological profile for lead. Atlanta, GA: U.S. Public Health Service, Centers for Disease Control, Agency for Toxic Substances and Disease Registry. ATSDR Publication TP-88/17.

28. CDC [1991]. Preventing lead poisoning in young children--a statement by the Centers for Disease Control - October 1991. Atlanta, GA: U.S. Department of Health and Human Service, Public Health Service, Centers for Disease Control.

29. CDC [1991]. Strategic plan for the elimination of childhood lead poisoning. Atlanta, GA: U.S. Department of Health and Human Service, Public Health Service, Centers for Disease Control.

30. Grandjean, P and Bach, E [1986]. Indirect exposures: the significance of bystanders at work and at home. Am. Ind. Hyg. Assoc. J. 47(12):819-824.

31. Farfel, MR, and Chisholm, JJ. [1990]. Health and environmental outcomes of traditional and modified practices for abatement of residential lead-based paint. American Jour of Pub Health, 80:10, 1240-1245.

32. EPA [1989]. Memorandum, OSWER Directive #9355.4-02, Interim guidance on establishing oil lead cleanup levels at superfund sites. Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, September 7, 1989.

33. MPCA [1991]. Lead abatement in soil. Minnesota Rules, chapter 4760, parts 4760.0010-4760.0050. St. Paul, MN: Minnesota Pollution Control Agency, Hazardous Waste Division, Rules Unit.

34. Wallace, LA [1985]. Organic chemicals in indoor air: a review of human exposure studies and indoor air quality studies. In: Indoor air and human health. Chelsea, MI: Lewis Publishers, pp 361-378.

35. Le, NT [1988]. Lead exposure from removing lead-based paint using heat guns. Washington, DC: Consumer Product Safety Commission (Structural Engineering and Physical Sciences Branch), Office of the Secretary.

36. CDC [1988]. Guidelines for evaluating surveillance systems. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, MMWR 1988:37 (suppl. no. S-5):[1-18].)

## X. AUTHORSHIP AND ACKNOWLEDGEMENTS

Primary field assistance provided by: Chuck McCammon, Steven Lee, Bill Daniels, NIOSH Denver Regional Office; Christopher Reh, Dan Almaguer, Bruce Hills, Greg Burr, Richard Stephenson, and Mary Newman, NIOSH, Hazard Evaluations and Technical Assistance Branch, Cincinnati.

Additional assistance provided by: Ellis Goldman, HUD; Jim Quinn, Speedwell, Inc.; Fred Eberly, Mark Montgomery, and Chip Harris, Dewberry & Davis; Roberta Spratt, and Dan Chute, Tracor Technology Resources.

| | |
|---|---|
| Report Prepared By: | Aaron Sussell, M.P.H.<br>Larry J. Elliott, M.S.<br>Deanna Wild, M.S., M.B.A.<br>Eugene Freund, M.D., M.S.P.H. |
| Originating Office: | Hazard Evaluations and Technical Assistance Branch<br>Division of Surveillance, Hazard Evaluations and Field Studies<br>NIOSH, Cincinnati, OH |
| Report Typed By: | Donna Humphries<br>Office Automation Assistant |

## XI. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report may be freely reproduced and are not copyrighted. Single copies of this report will be available for a period of 90 days from the date of this report from the NIOSH Publications Office, 4676 Columbia Parkway, Cincinnati, Ohio 45226. To expedite your request, include a self-addressed mailing label along with your written request. After this time, copies may be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161. Information regarding the NTIS stock number may be obtained from the NIOSH Publications Office at the Cincinnati address.

Copies of this report have been sent to:

1. Office for Policy Development and Research, HUD
2. Office of Lead-Based Paint Abatement and Poisoning Prevention, HUD
3. Director, OSHA
4. Director, Office of Pollution Prevention and Toxics, EPA
5. Dewberry & Davis
6. Tracor Technology Resources, Inc.
7. Speedwell, Inc.
8. Maryland Department of the Environment
9. Alabama Department of Public Health
10. Indiana State Board of Health
11. Colorado Department of Health
12. Washington Department of Social & Health Services
13. District of Columbia Department of Consumer and Regulatory Affairs
14. NIOSH Region VIII
15. NIOSH Region IV
16. Director, Center for Environmental Health and Injury Control, CDC
17. OSHA Region III
18. OSHA Region IV
19. OSHA Region VIII
20. OSHA Region X

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

TABLE 1

Air Sampling for Lead During Heat-gun Technique
HUD Lead-Based Paint Abatement Project
Denver and Indianapolis

October 3, 1989-December 6, 1989

HETA 90-070

| Sample Type | Location | Sample Time (min.) | Lead ($\mu g/m^3$) |
|---|---|---|---|
| | **Inside house** | | |
| PBZ | Denver | 420 | 6 |
| PBZ | Denver | 117 | 28 |
| PBZ | Denver | 293 | ND |
| PBZ | Indianapolis | 116 | 37 |
| PBZ | Indianapolis | 190 | 166 |
| PBZ | Indianapolis | 192 | 286 |
| PBZ | Indianapolis | 186 | 199 |
| PBZ | Indianapolis | 97 | 165 |
| PBZ | Indianapolis | 173 | 66 |
| PBZ | Indianapolis | 170 | 71 |
| Area | Denver | 420 | ND |
| Area | Denver | 420 | ND |
| Area | Denver | 331 | 20 |
| Area | Indianapolis | 154 | 19 |
| Area | Indianapolis | 289 | 116 |
| Area | Indianapolis | 367 | 33 |
| | **Outside house** | | |
| PBZ | Denver | 116 | ND |
| PBZ | Denver | 302 | ND |
| PBZ | Indianapolis | 190 | 3.3 |
| OSHA PEL - TWA | | | 50 |
| NIOSH REL - TWA | | | <100 |
| ACGIH TLV - TWA | | | 150 |

LOD 2, LOQ 6 $\mu g$/sample (Denver).
LOD 0.7, LOQ 2.2 $\mu g$/sample (Indianapolis).
ND Not detected, less than LOD.

TABLE 2

Measurements of Airborne Lead and Heat Gun Temperatures[1]
*HUD Lead-Based Paint Abatement Project*
Indianapolis, IN
March 14-15, 1990

HETA 90-070

| Sample Type | Operator/ Heat gun | Sample Time (min) | Heat Gun Temp Range (°F) | Lead (µg/m³) |
|---|---|---|---|---|
| **Single Gun** | | | | |
| PBZ | A | 32 | 750-950 | 27 |
| PBZ | A | 120 | 880-1015 | 262 |
| PBZ | A | 60 | 760-1035 | 41 |
| PBZ | B | 74 | 900-1042 | 65 |
| Area | A | 20 | 880-1015 | 58 |
| Area | A | 27 | 750-950 | 17 |
| Area | A | 58 | 760-1035 | 41 |
| Area | A | 50 | 900-1042 | 27 |
| **Double Gun** | | | | |
| PBZ | A | 52 | 450-615 | 52 |
| PBZ | B | 64 | 590-720 | 75 |
| PBZ | B | 171 | 648-735 | 35 |
| OSHA PEL-TWA | | | | 50 |
| NIOSH REL-TWA | | | | < 100 |
| ACGIH TLV-TWA | | | | 150 |

LOD 0.02 µg/sample
LOQ 0.036 µg/sample
[1]All samples were collected in the same room.

Table 3
Air Sampling for VOCs during Set-up and Heat-gun Methods
HUD Lead-Based Paint Abatement Project
Indianapolis, IN
November 2 and December 4-6, 1989

HETA 90-070

| Technique/ Sample Type | Time (min) | *n*-hexane[1] | total hexanes[1] | ethyl acetate[1] | *n*-butanol[1] | toluene[1] | xylene isomers[1] | butyl ether[1] | total HC[1] | OMCTS[1,2] | DMCPS[1,3] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Set-up (interior)** | | | | | | | | | | | |
| PBZ | 13 | 26.80 | 45.40 | ND | ND | ND | ND | ND | ND | ND | ND |
| **Heat gun (interior)** | | | | | | | | | | | |
| PBZ | 116 | ND | ND | ND | ND | ND | ND | ND | ND | 0.37 | 0.44 |
| PBZ | 170 | ND | ND | ND | ND | (0.05) | ND | ND | 3.91 | ND | ND |
| PBZ | 116 | ND | ND | ND | 0.25 | ND | ND | (0.11) | ND | ND | ND |
| PBZ | 173 | ND | ND | ND | ND | (0.04) | (0.04) | (0.08) | ND | ND | ND |
| PBZ | 107 | ND | ND | 0.47 | ND | ND | ND | ND | 2.84 | ND | ND |
| PBZ | 190 | ND | ND | ND | ND | ND | ND | ND | ND | ND | (0.07) |
| PBZ | 186 | ND | ND | ND | ND | ND | ND | ND | ND | ND | (0.04) |
| PBZ | 192 | ND | ND | ND | ND | ND | ND | ND | ND | ND | (0.05) |
| Area | 363 | ND | ND | ND | 0.15 | (0.02) | (0.02) | 0.14 | ND | ND | ND |
| **Heat gun (exterior)** | | | | | | | | | | | |
| PBZ | 190 | ND | ND | ND | ND | ND | ND | ND | ND | (0.04) | (0.05) |
| **Outside air** | | | | | | | | | | | |
| Area | 432 | ND | ND | ND | ND | (0.01) | ND | ND | ND | ND | ND |
| NIOSH REL-TWA | | | 350 | 1400 | C 50 | 375 | 435 | | | | |
| OSHA PEL-TWA | | | 1800 | 1400 | C 50 | 375 | 435 | | | | |
| ACGIH TLV-TWA | | | 1760 | 1440 | C 50 | 377 | 434 | | | | |
| LOD ug/sample | | 1 | 1 | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| LOQ ug/sample | | 3 | 3 | 15 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

[1]Values reported as mg/m$^3$.
[2]Octamethylcyclotetrasiloxane.
[3]Decamethylcyclopentasiloxane.
ND not detected, less than LOD.
( ) value between LOD and LOQ, result is approximate.

TABLE 4

Air Sampling for Lead During Set-up Technique
HUD Lead-Based Paint Abatement Project
Baltimore, MD and Denver, CO
October 25, 1989-February 1, 1990

HETA 90-070

| Sample Type | Location | Sample Time (min.) | Lead ($\mu g/m^3$) |
|---|---|---|---|
| | **Inside house** | | |
| PBZ | Baltimore | 203 | (4.2)[A] |
| PBZ | Baltimore | 165 | 10 |
| PBZ | Denver | 120 | ND[B] |
| Area | Baltimore | 247 | 36 |
| Area | Baltimore | 254 | (2.0)[A] |
| Area | Baltimore | 244 | (1.4)[A] |
| Area | Baltimore | 229 | (2.2)[A] |
| Area | Denver | 120 | ND[B] |
| Area | Denver | 120 | ND[B] |
| | **Outside house** | | |
| PBZ | Baltimore | 84 | 0.5[C] |
| Area | Baltimore | 72 | ND[A] |
| OSHA PEL-TWA | | | 50 |
| NIOSH REL-TWA | | | <100 |
| ACGIH TLV-TWA | | | 150 |

ND not detected
( ) value between LOD and LOQ

[A]LOD 0.7, LOQ 2.2 $\mu$g/sample.
[B]LOD 0.4, LOQ 1.2 $\mu$g/sample.
[C]LOD 0.02, LOQ 0.065 $\mu$g/sample.

TABLE 5

Air Sampling for Lead During Chemical Stripping Technique
HUD Lead-Based Paint Abatement Project
Indianapolis, IN
December 5, 1989-March 16, 1990

HETA 90-070

| Location and Sample Type | Sample Time (min.) | Lead ($\mu g/m^3$) |
|---|---|---|
| <u>Inside house</u> | | |
| PBZ | 55 | 0.7 |
| PBZ | 144 | 0.5 |
| PBZ | 174 | 4.0 |
| Area | 130 | 0.3 |
| Area | 133 | 0.4 |
| Area | 176 | 1.0 |
| <u>Outside house</u> | | |
| PBZ | 116 | 1.6 |
| PBZ | 104 | 2.6 |
| Area | 121 | 0.7 |
| OSHA PEL | | 50 |
| NIOSH REL | | <100 |
| ACGIH TLV | | 150 |

LOQ: 0.065 $\mu g$/sample

Table 6

Air Sampling for Alkaline Dust During Chemical Stripping
HUD Lead-Based Paint Abatement Project
Indianapolis, IN and Denver, CO
October 30, 1989 and December 6, 1989

| Sample Type | Location | Sample Time (min) | Alkaline Dust[1] (mg/m³) |
|---|---|---|---|
| PBZ | Denver | 172 | 0.5 |
| PBZ | Denver | 168 | 0.34 |
| PBZ | Indianapolis | 172 | ND |
| PBZ | Indianapolis | 167 | (0.12) |
| Area | Indianapolis | 176 | ND |
| OSHA PEL | | | 2 |
| NIOSH REL | | | 2 |
| ACGIH TLV | | | 2 |

ND not detected, less than the LOD.
( ) value between LOD and LOQ, result is approximate.

LOD: 0.04 mg/sample
LOQ: 0.12 mg/sample

TABLE 7

Air Sampling for Lead During Encapsulation Technique
HUD Lead-Based Paint Abatement Project
Indianapolis, IN
December 4-6, 1989

HETA 90-070

| Sample Type | Sample Time (min.) | Lead ($\mu g/m^3$) |
|---|---|---|
| PBZ | 376 | (1.3) |
| PBZ | 174 | 11 |
| PBZ | 88 | (8.5) |
| OSHA PEL - TWA | | 50 |
| NIOSH REL - TWA | | <100 |
| ACGIH TLV - TWA | | 150 |

( ) sample value between LOD and LOQ, result is approximate.

LOD: 0.7 $\mu$g/sample.
LOQ: 2.2 $\mu$g/sample.

Table 8

Air Sampling for Lead During Replacement Technique
HUD Lead-Based Paint Abatement Project
Baltimore, MD and Indianapolis, IN
December 5 and February 1, 1990

HETA 90-070

| Sample Type | Sample Time (min.) | Lead ($\mu g/m^3$) |
|---|---|---|
| PBZ | 121 | 0.62[a] |
| PBZ | 104 | (3.8)[b] |
| PBZ | 97 | (10)[b] |
| Area | 92 | (5.4)[b] |
| Area | 70 | (5.0)[b] |
| OSHA PEL - TWA | | 50 |
| NIOSH REL - TWA | | <100 |
| ACGIH - TWA | | 150 |

( ) sample value between LOD and LOQ, result is approximate.

[a]LOD, LOQ: 0.02, 0.065 $\mu$g/sample.
[b]LOD, LOQ: 0.05, 4.9 $\mu$g/sample.

TABLE 9

Results of Short-term Sampling for $CO_2$ and CO during Abatement
HUD Lead-Based Paint Abatement Project
Indianapolis, IN
December 4-6, 1989

HETA 90-070

| Sampling Location House-Room | Date | Sampling Time | $CO_2$[1] (ppm) | CO[2] (ppm) | Comments[3] |
|---|---|---|---|---|---|
| A-Kitchen | 12/4/89 | 9:25 | 2,500 | --- | Propane heater in kitchen started at 0630 hours. Heat gun, encapsulation and set up |
| A-Kitchen | 12/4/89 | 10:20 | 2,700 | --- | activities - one worker each. Outdoor temperature 37 °F. |
| A-Outdoors | 12/4/89 | 9:25 | 225 | --- | |
| A-Living Room | 12/4/89 | 10:25 | 350 | --- | Unoccupied adjacent room. |
| A-Kitchen | 12/4/89 | 16:40 | 225 | --- | Propane heater off. Large negative air unit in room on. |
| A-Kitchen | 12/6/89 | 9:00 | 600 | ND | One propane heater on. Negative air unit operating. No abatement work. |
| A-Kitchen | 12/6/89 | 9:15 | 1,800 | ND | One propane heater on. Negative air unit off. No abatement work. |
| A-Kitchen | 12/6/89 | 10:00 | 400 | ND | One propane heater on. Negative air unit operating. Encapsulation technique. |
| B-Living Room | 12/5/89 | 9:10 | 800 | ND | No propane heater. Three heat guns in use, small negative air unit on in the room. |
| C-Living Room | 12/6/89 | 9:00 | 700 | --- | No propane heater. Four workers performing chemical stripping. Room was provided with |
| C-Living Room | 12/6/89 | 9:50 | 775 | --- | small negative air unit. |
| C-Living Room | 12/6/89 | 10:20 | 825 | --- | " |
| C-Living Room | 12/6/89 | 11:30 | 775 | --- | " |
| C-Outdoors | 12/6/89 | 10:20 | 225 | --- | |
| D-Kitchen | 12/6/89 | 10:40 | >3,000[4] | 30 | Two propane heaters in other rooms started at 0820 hours. Set-up technique. One window |
| D-Living Room | 12/6/89 | 10:55 | >3,000 | --- | in kitchen opened 2 inches. |
| D-Outdoors | 12/6/89 | 11:15 | 300 | ND | |
| D-Kitchen | 12/6/89 | 14:00 | 600 | 10 | One propane heater in house. All windows were opened 2-3 inches, set-up technique. |
| D-Hallway | 12/6/89 | 14:00 | 425 | 10 | " |

[1]Measured with Dräger® 0.01% /a tubes
[2]Measured with Dräger® 5/c tubes
[3]Window and door openings were sealed with 6-mil polyethylene, unless otherwise noted.
[4]Greater than the maximum concentration limit of the tube

ND Not detected, less than the LOQ
--- No measurement taken.

TABLE 10

Results of Soil and Paint Bulk Samples
HUD Lead-Based Paint Abatement Project
Baltimore, MD
February 1, 1990

HETA 90-070

| Sample Type | Location | Lead Concentration | |
|---|---|---|---|
| | | ppm | Percent |
| soil | Front yard-1' from porch | 75 | – |
| soil | Front yard-10' from porch | 220 | -- |
| soil | Front yard-30' from porch | 170 | -- |
| paint | Closet door[1] | 1,100 | 0.11 |
| paint | Kitchen cabinet[1] | 3,400 | 0.34 |
| paint | Porch column[2] | 2,400 | 0.24 |
| paint | Baseboard[2] | 21,000 | 2.1 |

LOD = 10 μg/g
LOQ = 33 μg/g

[1]Not scheduled for abatement.
[2]Scheduled for abatement.

TABLE 11

Results of Surface Sampling for Lead
HUD Lead-Based Paint Abatement Project
Indianapolis, Indiana
February 1, 1990

HETA 90-070

| Location | Lead $\mu g/ft^2$ | |
|---|---|---|
| | **Before HEPA vacuum** | **After HEPA vacuum** |
| Front Porch | 990 | 150 |
| Porch balustrade-E. side | 480 | 250 |
| Porch balustrade-S. side | 13,000 | 1300 |
| Floor-middle of porch | 10,000 | 990 |
| Floor-just outside DS[1] | 4,200 | -- |
| Floor-3-4' outside DS | | |
| Decon Structure (DS) | -- | 1800 |
| DS floor - "clean" slide | -- | 46 |
| DS floor - "dirty" slide | -- | [12] |
| DS wall - "clean" slide | -- | 460 |
| DS wall - "dirty" slide | | |
| HUD clearance criteria-floors | | 200 |
| HUD clearance criteria-walls | | 500 |

[ ] sample value between LOD and LOQ, result is approximate.

-- sample lost or no sample collected

LOD 3 $\mu g$/sample
LOQ 9 $\mu g$/sample

[1]decontamination structure

Table 12
PBZ Air Sampling for Lead by Method or Activity
Data Collected by HUD Contractors
HUD Lead-Based Paint Abatement Project
HETA 90-070

| Abatement Method/Activity | N Obs. | PBZ Lead Concentrations (µg/m³) Minimum | Maximum | Geometric Mean | Geometric SD |
|---|---|---|---|---|---|
| Abrasive | 28 | 0.4 | 399 | 8.8 | 7.6 |
| Chemical Removal | 291 | 0.4 | 476 | 3.3 | 4.1 |
| Cleaning | 138 | 0.4 | 588 | 1.9 | 3.6 |
| Encapsulation | 83 | 0.4 | 26 | 1.4 | 2.8 |
| Enclosure | 50 | 0.4 | 72 | 1.7 | 3.2 |
| Final Cleaning | 56 | 0.9 | 36 | 2.1 | 2.8 |
| Heat Gun | 360 | 0.4 | 916 | 6.4 | 4.7 |
| Precleaning | 31 | 0.9 | 11 | 1.5 | 2.2 |
| Replacement | 110 | 0.4 | 121 | 2.5 | 3.9 |
| Set Up | 153 | 0.4 | 137 | 1.5 | 3.1 |
| Other[1] | 15 | 0.4 | 207 | 1.9 | 5.1 |
| Missing[2] | 87 | --- | --- | --- | --- |
| Total | 1402 | 0.4 | 916 | 3.1 | 4.4 |
| OSHA PEL-TWA | | | 50 | | |
| NIOSH REL-TWA | | | <100 | | |
| ACGIH TLV-TWA | | | 150 | | |

[1]Other abatement activities.
[2]Samples with no identified method/activity are not reported.

Laboratory-assigned LOQ: 0.4 µg/m³

Table 13
Area Air Sampling for Lead by Method or Activity
Data collected by HUD Contractors
HUD Lead-Based Paint Abatement Project
HETA 90-070

| Abatement Method/Activity | N Obs. | Area Lead Concentrations (µg/m³) Minimum | Maximum | Geometric Mean | Geometric SD |
|---|---|---|---|---|---|
| Abrasive | 23 | 0.4 | 131 | 3.1 | 6.0 |
| Chemical Removal | 240 | 0.4 | 132 | 1.9 | 3.3 |
| Cleaning | 133 | 0.4 | 299 | 1.6 | 3.8 |
| Encapsulation | 64 | 0.4 | 68 | 1.0 | 3.0 |
| Enclosure | 55 | 0.4 | 28 | 1.2 | 3.0 |
| Final Cleaning | 44 | 0.9 | 429 | 1.9 | 3.2 |
| Heat Gun | 257 | 0.4 | 1296 | 4.3 | 5.3 |
| Precleaning | 13 | 0.9 | 7 | 1.4 | 1.9 |
| Replacement | 115 | 0.4 | 124 | 1.8 | 3.8 |
| Set-Up | 143 | 0.4 | 59 | 1.4 | 2.9 |
| Other[1] | 25 | 0.4 | 552 | 1.2 | 7.1 |
| Missing[2] | 21 | — | — | — | — |
| Total | 1233 | 0.4 | 1296 | 2.0 | 4.2 |
| OSHA PEL-TWA | | | 50 | | |
| NIOSH REL-TWA | | | <100 | | |
| ACGIH TLV-TWA | | | 150 | | |

[1]Other abatement activities.
[2]Samples with no method or activity identified are not reported.

Laboratory-assigned LOQ: 0.4 µg/m³

Table 14

Percentiles for PBZ Sampling for Lead by Method
Data Collected by HUD Contractors
HUD Lead-Based Paint Demonstration Project

HETA 90-070

| Abatement Method | Percentiles-lead concentrations[1] 5% | 10% | 50% | 90% | 95% | 99% |
|---|---|---|---|---|---|---|
| Abrasive | 0.4 | 0.9 | 7 | 177 | 196 | 399 |
| Chemical Removal | 0.4 | 0.9 | 3 | 20 | 48 | 148 |
| Cleaning | 0.4 | 0.4 | 1 | 8 | 24 | 104 |
| Encapulation | 0.4 | 0.4 | 1 | 6 | 8 | 26 |
| Enclosure | 0.4 | 0.4 | 1 | 7 | 9 | 72 |
| Final Cleaning | 0.9 | 0.9 | 1 | 7 | 17 | 36 |
| Heat Gun | 0.6 | 0.9 | 6 | 58 | 78 | 202 |
| Precleaning | 0.9 | 0.9 | 1 | 6 | 9 | 11 |
| Replacement | 0.4 | 0.4 | 2 | 20 | 33 | 55 |
| Set-Up | 0.4 | 0.4 | 1 | 6 | 11 | 53 |
| Other[2] | 0.4 | 0.4 | 1 | 18 | 207 | 207 |
| Missing[3] | | | | | | |

[1] All values expressed as $\mu g/m^3$.
[2] Other abatement activities.
[3] Samples with no method or activity identified are not reported.

Laboratory-assigend LOQ: 0.4 $\mu/m^3$

Table 15

Data collected by HUD Contractors
Airborne Lead–Mean Values for
Combinations of Method and Contractor
HUD Lead-Based Paint Abatement Project

HETA 90-070

| Abatement Contractor | Abrasive | Chemical Removal | Cleaning | Encap | Enclose | Final Cleaning | Heat Gun | Preclean | Replace | Set Up | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | 6.3 | 10 | | 1.0 | 6.2 | 27 | | 4.4 | 5.4 | 14 |
| B | | 3.0 | 1.0 | 2.2 | 1.9 | 0.9 | 11 | | 3.4 | 2.4 | |
| C | | 5.2 | 1.4 | 0.9 | 1.7 | 2.0 | 21 | | 9.5 | 1.9 | 0.8 |
| D | 91 | 2.6 | 7.7 | 5.0 | | 70 | 43 | | 1.0 | 1.2 | |
| E | 54 | 14 | 4.4 | 3.2 | 1.2 | 2.8 | 31 | | 3.0 | 1.7 | 2.0 |
| F | | 6.8 | 1.6 | 2.4 | 6.0 | 1.0 | 8.2 | 2.3 | 9.3 | 7.3 | 0.8 |
| G | | 2.3 | 3.7 | 1.5 | | | 4.0 | 1.5 | 5.0 | 2.5 | 1.2 |
| H | 6.0 | 4.3 | | 1.7 | | | | | 44 | 2.4 | 0.5 |
| I | | 3.2 | 2.1 | 2.3 | 12 | | 10 | 2.5 | 4.4 | 2.1 | |
| J | 9.1 | 2.7 | 22 | 2.6 | | | 0.5 | 5.7 | 9.1 | 4.4 | 0.7 |
| K | | 2.2 | 11 | 1.4 | | 1.0 | 30 | | 1.9 | 2.5 | 97 |
| L | 22 | 12 | 9.4 | 6.0 | 2.0 | | 8.2 | | 14 | 3.7 | 310 |
| P-value[1] | 0.0005 | >0.05 | >0.05 | 0.001 | >0.05 | 0.0001 | 0.0002 | >0.05 | 0.02 | 0.0007 | <.0001 |

All values reported in μg/m³.

(shaded) No observations.

[1]P-value of ANOVAS performed for each abatement method (Type III).

Table 16

Descriptive Statistics for Significant Variables
in Analysis of Variance by Housing Unit
Data Provided by HUD Contractors
HUD Lead-Based Paint Abatement Demonstration

HETA 90-070

| Variables | Units (N) | Measurement Units | Minimum | Maximum | Mean | S.D. |
|---|---|---|---|---|---|---|
| **INDEPENDENT** | | | | | | |
| Mean soil lead pre-abatement | 134 | ppm | 73 | 4841 | 736 | 724 |
| mean paint lead concentration | 167 | $mg/cm^2$ | -0.1 | 7.9 | 1.4 | 1.3 |
| total square feet abated | 169 | $ft^2$ | 12 | 5140 | 1456 | 1054 |
| **DEPENDENT** | | | | | | |
| mean air lead concentration | 163 | $\mu g/m^3$ | 0.7 | 105 | 9.4 | 15 |

Table 17

Mean Airborne Lead Concentration vs. Unit Abatement Strategy
Data for 162 Housing Units Collected by HUD Contractors
HUD Lead-Based Paint Abatement Demonstration

HETA 90-070

| ABATEMENT STRAGEGY | Units (N) | Mean Airborne Lead ($\mu g/m^3$) by Housing Unit | | | |
|---|---|---|---|---|---|
| | | Mean | Minimum | Maximum | S.D. |
| ABRASIVE | 24 | 8.9 | 1.0 | 64 | 14 |
| CHEMICAL REMOVAL | 20 | 12 | 1.5 | 68 | 19 |
| ENCAPSULATION | 37 | 5.4 | 0.9 | 33 | 7.0 |
| ENCLOSURE | 17 | 6.2 | 0.9 | 23 | 6.6 |
| **HEAT GUN[1]** | **17** | **22** | **0.9** | **105** | **26** |
| HEAT GUN - NA | 14 | 12 | 1.9 | 48 | 13 |
| REPLACEMENT | 18 | 8.1 | 0.7 | 67 | 15 |
| REPLACEMENT - NA | 15 | 5.0 | 1.3 | 23 | 5.5 |
| MISSING[2] | 29 | | | | |

[1]Significantly different than all other strategies ($p < 0.05$)
[2]Missing one or more variables in model.

## FIGURE 1
## SUMMARY OF NIOSH ANALYSES OF HUD ENVIRONMENTAL DATA

| Analysis Number | Analysis Type (p-value) | Dependent Variable | Independent Variables (p=value) | |
|---|---|---|---|---|
| 1 | ANOVA ($p=0.0001$) | airborne lead concentration | abatement method[1,6] | |
| | | (area and PBZ samples, n=2611) | contractor | |
| | | | contractor * method[2] | ($p=0.0001$) |
| | | | housing unit (nested under contractor) | ($p=0.0001$) |
| 2 | ANCOVA ($p=0.0001$) | log mean airborne lead concentration | abatement strategy | ($p=0.0001$) |
| | | by housing unit | city | ($p>0.05$) |
| | | (area and PBZ samples, n=128) | contractor | ($p>0.05$) |
| | | | median paint condition[3] | ($p>0.05$) |
| | | | total square feet abated[4] | ($p>0.05$) |
| | | | mean paint lead concentration[5] | ($p=0.0003$) |
| | | | mean pre-abatement soil lead concentration | ($p=0.0005$) |
| 3 | ANCOVA ($p=0.12$) | mean change in soil lead concentration | abatement strategy | ($p>0.05$) |
| | | by housing unit | city | ($p>0.05$) |
| | | (n=130) | contractor | ($p>0.05$) |
| | | | median paint condition[3] | ($p>0.05$) |
| | | | total square feet abated[4] | ($p>0.05$) |
| | | | mean paint lead concentration[5] | ($p>0.05$) |

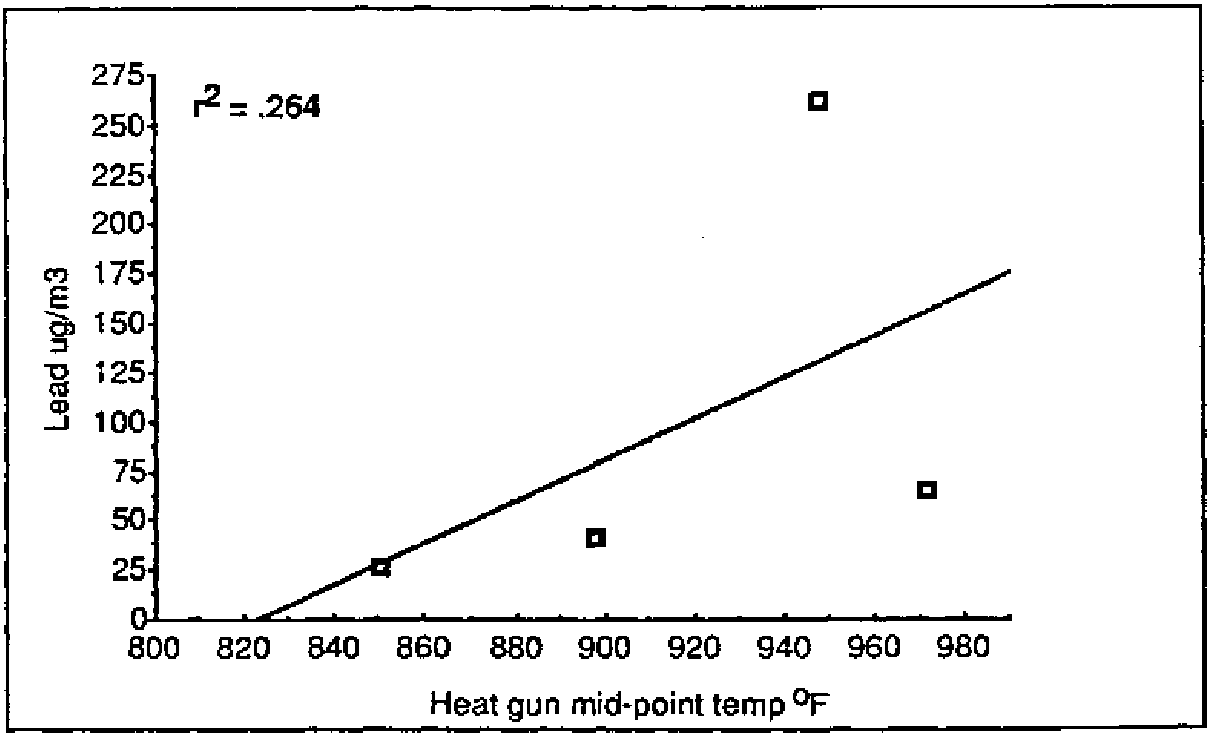
ANOVA=analysis of variance, ANCOVA=analysis of covariance

1 NIOSH reclassified-see Appendix A.
2 Contractor*method interaction term included after preliminary ANOVA.
3 NIOSH reclassified-see Appendix B.
4 NIOSH calculated total-see Appendix C.
5 Measured by AAS (if available) or XRF.
6 Separate ANOVA were performed subsequently for each method, see Table 15.

Figure 2

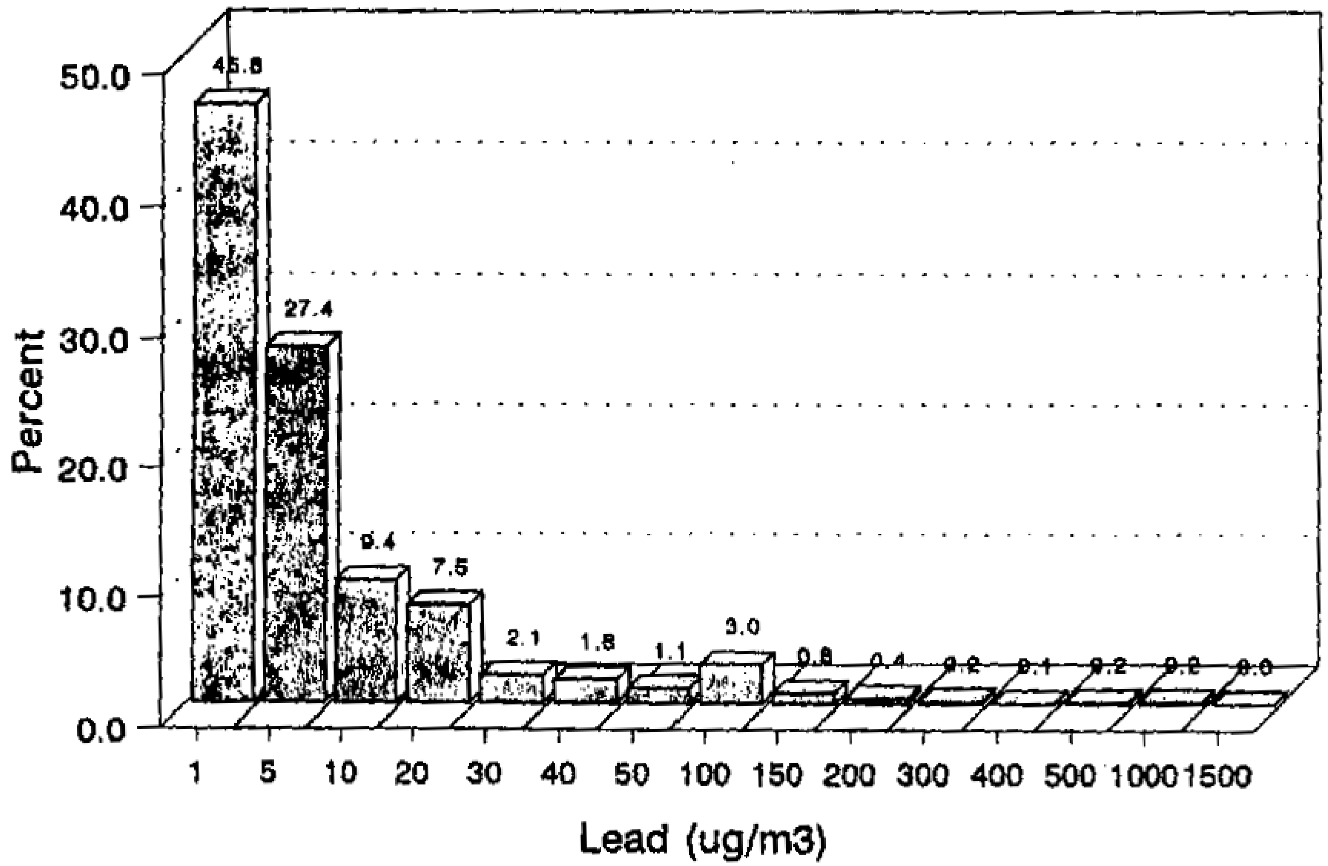
Heat Gun Temperature vs. PBZ Airborne Lead Concentration
During the Heat Gun Method
HUD Lead-Based Paint Abatement Demonstration
Indianapolis, IN
March 14-15, 1990

HETA 90-070



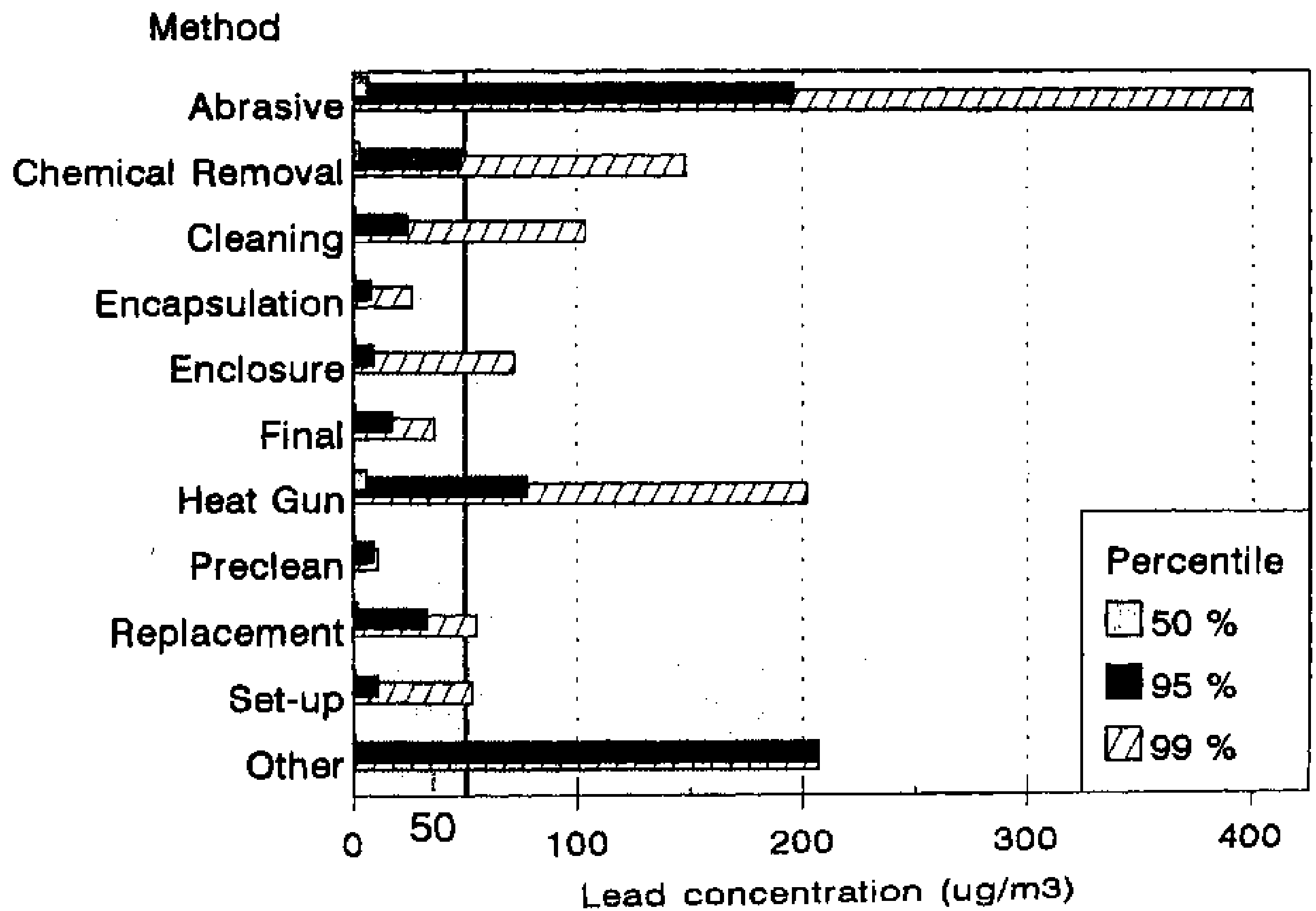
## Figure 3

**Distribution of PBZ and Area Airborne Lead Concentrations**
**2635 Samples Collected by HUD Contractors**
**HUD Lead-Based Paint Abatement Demonstration**



# Figure 4

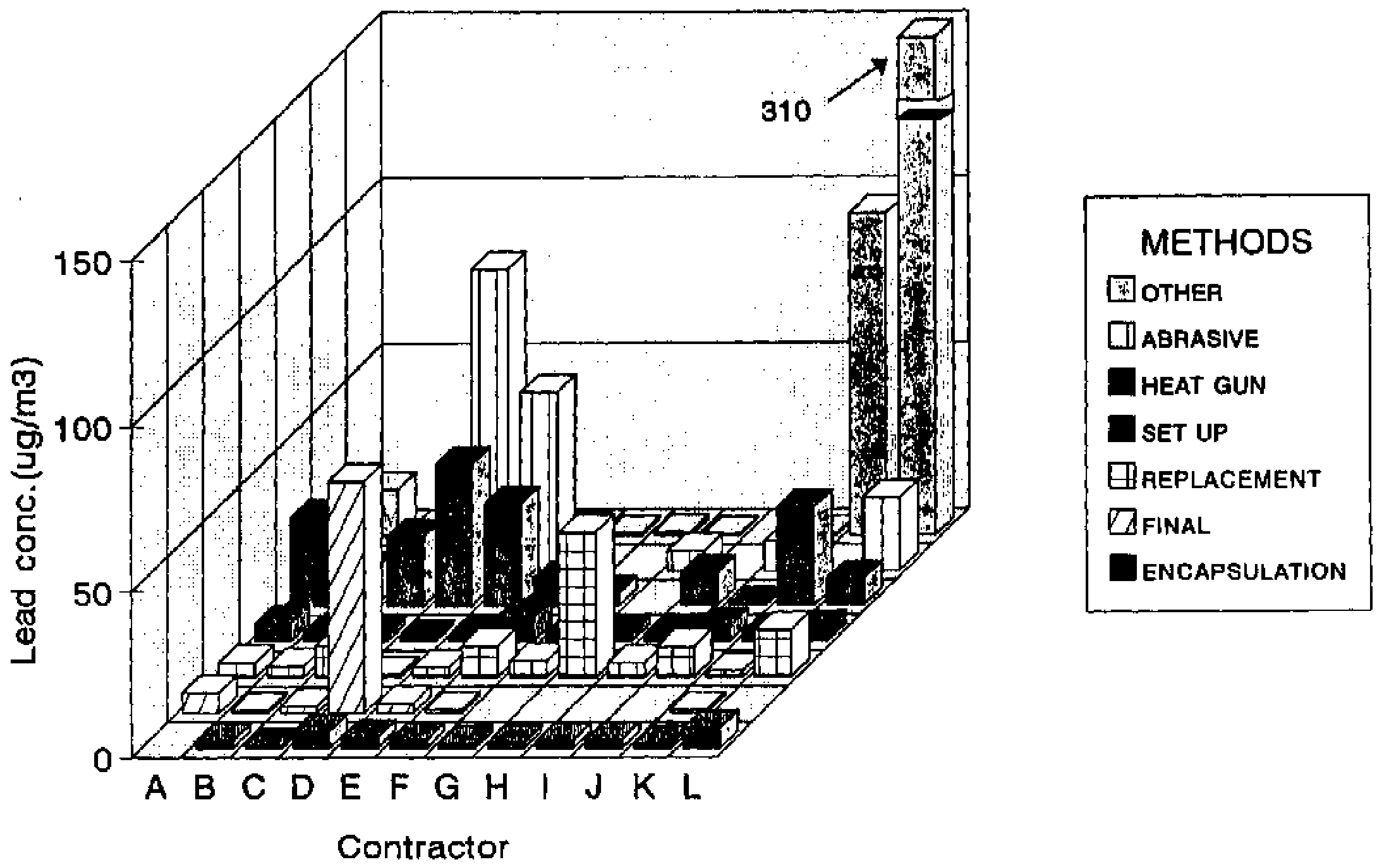
## Percentiles for Personal Lead Exposures by Method
## 1402 PBZ Samples Collected by HUD Contractors
## HUD Lead-Based Paint Demonstration Project



## Figure 5

**Mean Airborne Lead Concentrations for Abatement Methods with Significant Contractor Variation ($p<0.05$)**

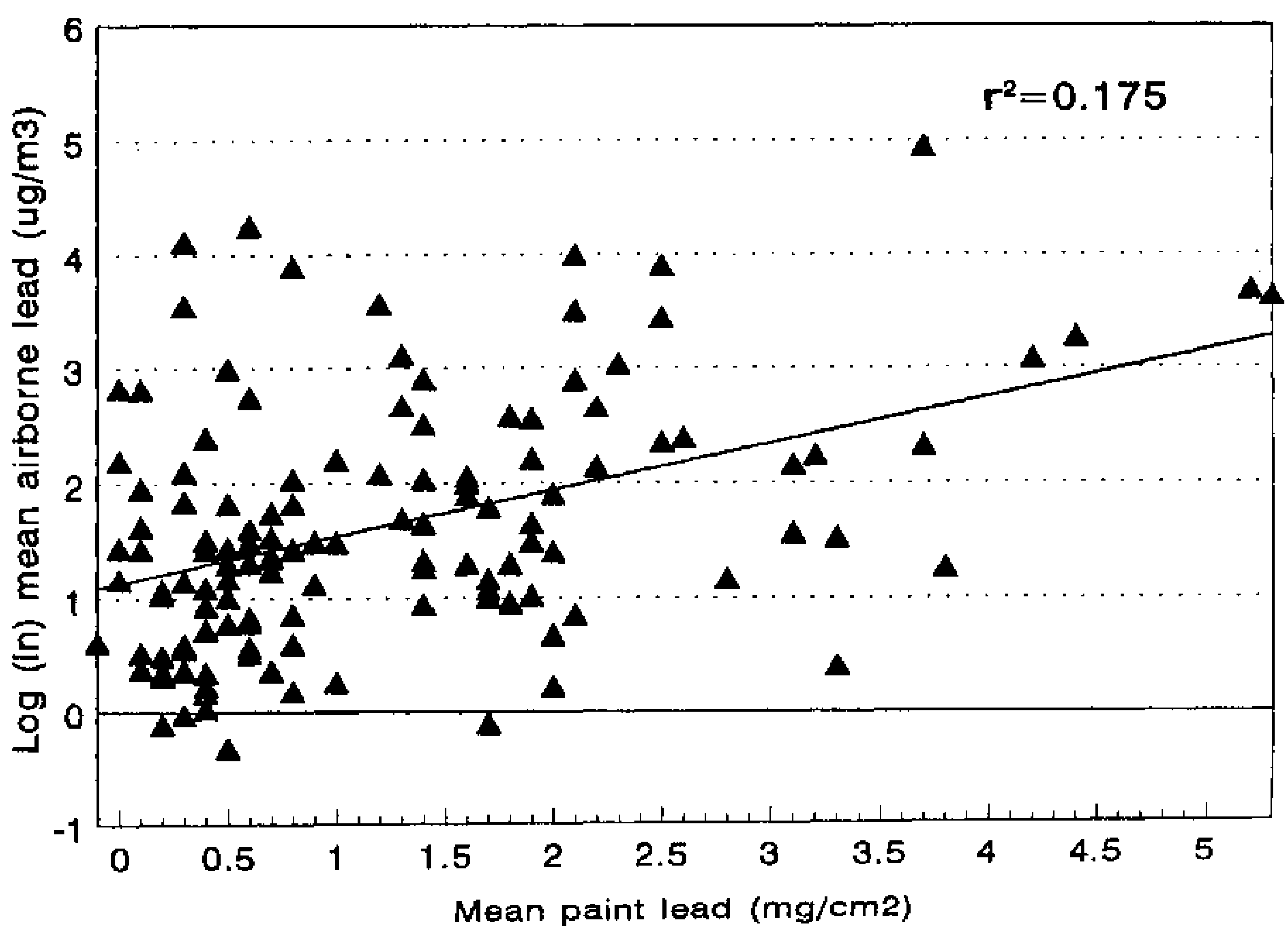
**2611 PBZ and Area Samples Collected By HUD Contractors**



## Figure 6

**Mean Paint- vs. Log Mean Airborne-Lead Concentrations for 131 Housing Units Abated**

**Data Collected by Hud Contractors**



## Figure 7
**Distribution of Mean Soil Lead Concentrations**
**Pre- and Post-Abatement for 130 Units**
**Data Collected by HUD Contractors**

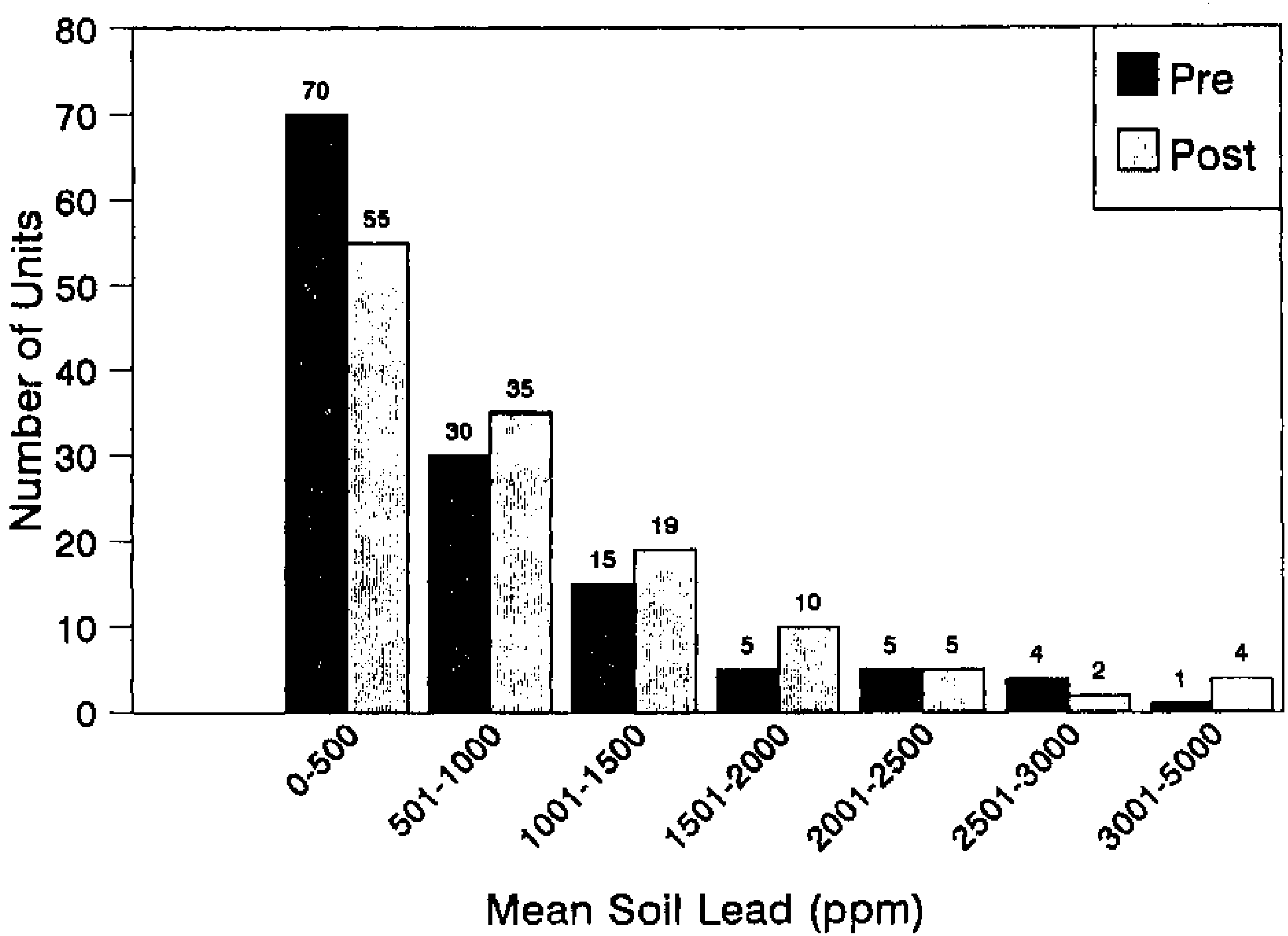
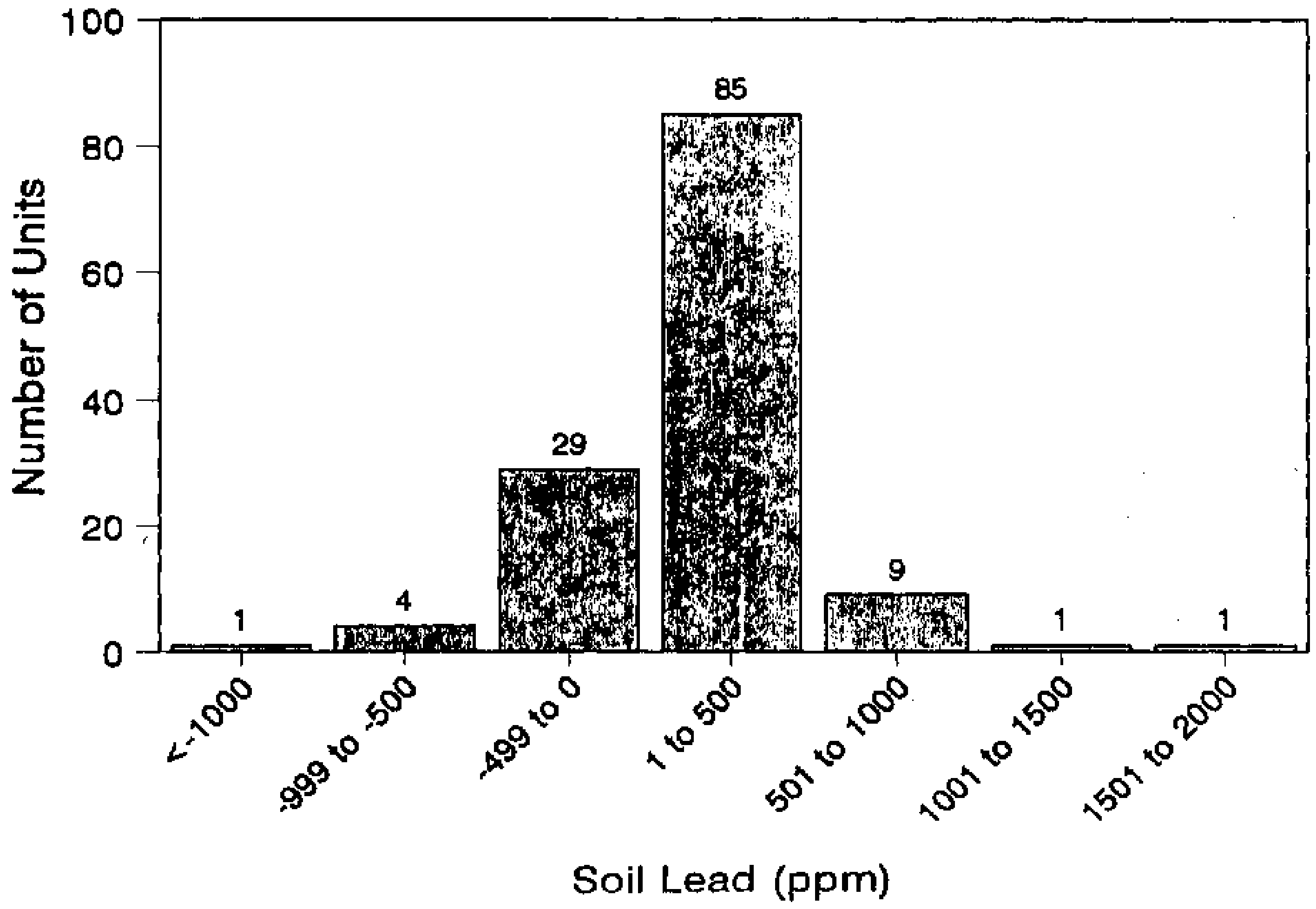


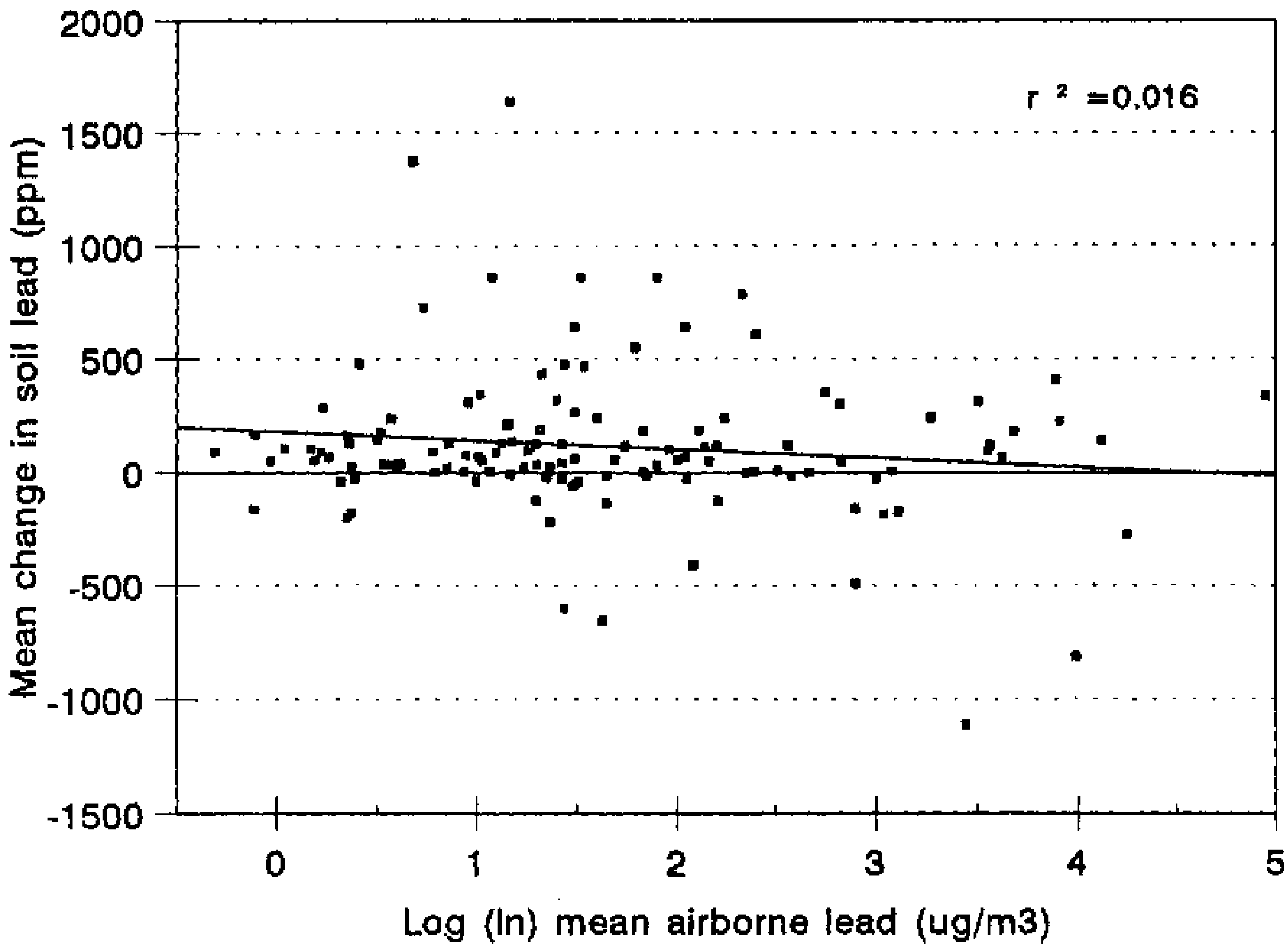
Figure 8

Distribution of Mean Change in Soil
Lead Concentration for 130 Abated Units
Data Collected by HUD Contractors



## Figure 9

Log Mean Airborne Lead vs. Mean
Change in Soil Lead for 128 Housing Units
Data Collected by HUD Contractors



Appendix A

NIOSH Reclassification of Abatement Methods
for 2635 PBZ and Area Air Sample Results Provided by HUD Contractors
HUD Lead-Based Paint Abatement Demonstration

HETA 90-070

| NIOSH METHOD[1] | FREQUENCY | PERCENT | ORIGINAL METHOD[2] |
|---|---|---|---|
| ABRASIVE | 27 | 1.0 | ABRASIVE |
| ABRASIVE | 24 | 0.9 | NEEDLE |
| CHEMICAL REMOVAL | 531 | 20.2 | CHEM |
| CLEANING | 232 | 8.8 | CLEANING |
| CLEANING | 11 | 0.4 | HEPA |
| CLEANING | 28 | 1.1 | WASH |
| ENCAPSULATION | 125 | 4.7 | ENCAP |
| ENCAPSULATION | 22 | 0.8 | PAINT |
| ENCLOSURE | 105 | 4.0 | ENCLOSE |
| FINAL | 100 | 3.8 | FINAL |
| HEAT GUN | 617 | 23.4 | HAND |
| OTHER | 5 | 0.2 | CAULK |
| OTHER | 6 | 0.2 | DECON |
| OTHER | 12 | 0.5 | DEMO |
| OTHER | 1 | 0.0 | MONITOR |
| OTHER | 3 | 0.1 | NEG AIR |
| OTHER | 1 | 0.0 | REPAIR |
| OTHER | 10 | 0.4 | SAWING |
| OTHER | 2 | 0.1 | WASTE |
| PRECLEANING | 44 | 1.7 | PRECLEAN |
| REPLACEMENT | 225 | 8.5 | REPLACE |
| SET UP | 296 | 11.2 | SETUP |
| MISSING | 208 | 7.9 | (none) |
| Total | 2635 | 100 | |

[1]Method categories assigned by NIOSH for analysis of sampling data.
[2]Original method categories in data provided collected by HUD contractors.

## Appendix B

NIOSH Reclassification of Paint Condition Ratings
Data Provided by HUD Contractors
HUD Lead-Based Paint Abatement Demonstration

HETA 90-070

**SUBJECTIVE RATING OF PAINT CONDITION**

| Paint Condition[1] | Original Code | NIOSH Coding |
|---|---|---|
| Not Painted | 0 | 0 |
| Good | 4 | 1 |
| Caulking | 1 | 2 |
| Peeling | 2 | 3 |
| Damaged | 3 | 4 |

[1] "COND" field in spreadsheet files provided to NIOSH; data collected by HUD contractors.

## Appendix C

### Determination of Total Square Feet Abated from Substrate Information Data Collected by HUD Contractors HUD Lead-Based Paint Abatement Demonstration

HETA 90-070

| SUBSTRATE | UNITS |
|---|---|
| Door | each[1] |
| Window | each[2] |
| Windowsill | linear feet[3] |
| Window trim | linear feet[3] |
| Balustrade | square feet |
| Column | square feet |
| Wall | square feet |
| Door frame | linear feet[3] |
| Foundation | square feet |
| Handrail | linear feet[3] |
| Soffit | square feet |
| Baseboard | linear feet[3] |
| Mechanical Enclosure | square feet |
| Pipe | linear feet[3] |
| Ceiling | square feet |
| Stair Tread | square feet |
| Other | square feet |
| Floor | square feet |
| Gutters | linear feet[3] |
| Ceiling molding | linear feet[3] |
| Chair rail | linear feet[3] |
| Assumptions for units conversions based on data collected by HUD consultants. | |

[1]Converted to square feet by assuming 42 $ft^2$/door
[2]Converted to square feet by assuming 12 $ft^2$/window
[3]Converted to square feet by assuming 0.33 ft average width

Notes:

Total square feet abated (by unit) - total of interior and exterior square feet to be abated (measurements for all substrates converted to square feet).

Total exterior feet abated (by unit) - total of exterior square feet to be abated (measurements for all substrates converted to square feet).