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SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance from Ohio University, Athens, Ohio, in December 1991. The request was for a NIOSH evaluation of worker exposures and cleaning effectiveness during a lead-based paint (LBP) cleaning pilot project. The pilot project took place in unoccupied buildings which were part of a former state hospital complex, built in the late 1800's. The University planned to clean gross lead contamination in the buildings prior to future renovation work; including loose and peeling LBP on plaster walls and ceilings, wood trim and doors; and paint chips and dust accumulated on floors. The LBP cleaning pilot project was designed to evaluate three cleaning methods under consideration by the university. The methods (and designations) used were: a) dry scraping followed by broom sweeping (dry sweeping)--this was selected to demonstrate exposures with no use of engineering or work practice controls; b) wet scraping (painted surfaces were wetted with water mist) followed by high-efficiency particulate air-filtered (HEPA) vacuuming (wet HEPA); and c) wet scraping followed by HEPA vacuuming, with a HEPA-filtered air-filtration device placed in the room to exhaust room air to the outside (wet HEPA/AFD). The final step for each of the methods was wet-mopping of the floor (once) with fresh tri-sodium phosphate detergent solution; using a new string mop head for each room cleaned.

An asbestos and lead abatement contractor provided six workers, for one day, to the University for the pilot project. The pilot project size was limited to 18 rooms, the estimated maximum number that could be cleaned with the available labor. The rooms, of similar size (most were about 9 ft x 15 ft) and condition, were selected non-randomly from two adjoining buildings at the outset of the study. Three two-man work crews cleaned six rooms each; the crews cleaned two rooms consecutively with each of the three methods. The work crew assignments were made randomly.

Two samples of loose or peeling paint were collected in each room prior to cleaning. Pre- and post-cleaning floor surface samples were collected for lead near the center of each room, and in the halls two feet outside the doorways. Two personal breathing zone (PBZ), and one area air sample were collected in each room during cleaning.

The overall mean paint lead concentration was 4.3% (range: 2.8% - 19%). Pre-cleaning, the rooms had a mean (floor) surface lead concentration of 2600 micrograms per square foot (µg/ft^2) (range: 620 - 8200 µg/ft^2). Overall, the post-cleaning room surface lead concentrations were significantly reduced, mean 1300 µg/ft^2 (range: 250 - 4200 µg/ft^2). Hall surface lead concentrations, which were generally higher than rooms, were not changed significantly overall by the cleaning (cleaning hallways was not an objective of the project). Variability of adjacent surface samples collected in six rooms pre- and post-cleaning was quite high. All six workers' hands were sampled for lead at the lunch break and the end of shift; lead concentrations on all workers' hands were markedly higher

before handwashing with soap and water (range: 120 - 1500 µg) than after washing (range: 14 to 240).

NIOSH performed analyses of covariance (ANCOVAs) on the data collected in the pilot project. Overall, the method, mean paint lead concentration, pre-cleaning surface lead concentration and crew were significantly associated with observed variations in mean PBZ exposure and area airborne lead (in two separate ANCOVAs), p=0.023 and 0.015, respectively. The adjusted (least squares) mean PBZ exposure for dry sweeping (107 micrograms per cubic meter [$\mu g/m^3$]) was significantly greater than that for wet HEPA (34 $\mu g/m^3$), but not wet HEPA/AFD (56 $\mu g/m^3$), the latter two did not differ significantly. The adjusted mean PBZ exposure for one of the three work crews was significantly less than either of the other two, p=0.026 and 0.045, respectively; indicating the importance of work practices. Mean PBZ exposures (per room) were quite well correlated with room area lead concentrations ($r^2=0.72$).

It has been suggested that home renovators test surfaces for LBP in older housing as a means to determine the potential for personal lead overexposures during various renovation activities. However, the correlation between mean paint lead concentrations and mean PBZ exposures was very weak ($r^2=0.13$), as were the corresponding correlations by method. The mean PBZ exposure was greater than 50 $\mu g/m^3$ in four of the nine rooms with mean paint lead concentrations less than 0.5%.

Overall, the method, mean area airborne lead concentration, mean paint lead concentration, pre-cleaning surface lead concentration, and crew were not significantly associated with observed variation in (log) room post-cleaning surface lead concentrations. The adjusted (least squares) means for dry sweeping (250 $\mu g/ft^2$), wet HEPA (1500 $\mu g/ft^2$) and wet HEPA/AFD (2100 $\mu g/ft^2$) did not differ significantly, p=0.15, due in large part to the amount of variability observed. Similar results were obtained for hall post-cleaning surface lead concentrations.

Workers were potentially overexposed to lead during the three LBP cleaning methods (designated dry sweeping, wet HEPA, and wet HEPA/AFD) evaluated during a pilot project in buildings contaminated with deteriorated lead-based paint. Of the methods evaluated, the wet HEPA method appeared to offer the best control for worker exposures and area airborne lead concentrations. PBZ and area lead concentrations during cleaning were dependent on several variables, including the method, mean paint lead concentration, pre-cleaning surface lead concentration, and crew. The provision of air filtration devices in rooms with the wet HEPA method did not provide any additional reduction of worker exposures or room airborne lead concentrations. Overall, room surface lead concentrations were significantly reduced by the cleaning; the cleaning effectiveness of the three methods did not differ significantly. Recommendations to reduce worker lead exposures during future LBP cleaning are provided.

KEYWORDS: SIC 1799 (special trade contractors, not elsewhere classified) , lead-based paint abatement, lead, cleaning methods, renovation, construction industry.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance from Ohio University, Athens, Ohio, in December 1991. The request was for an evaluation of methods for cleaning buildings grossly contaminated with deteriorated lead-based paint (LBP). After discussions with the University, NIOSH agreed to evaluate worker exposures and cleaning effectiveness, during a pilot project for three LBP cleaning methods which were under consideration by the University. The cleaning objective was to clean gross lead contamination in the buildings, which consisted of loose and peeling LBP on plaster walls and ceilings, wood trim and doors; and paint chips and dust accumulated on the terrazzo floors. The results of the study are of interest because many construction workers potentially perform similar activities during renovation and implementation of interim controls* for LBP hazard reduction in public housing.

One NIOSH site visit, from April 29 to May 1, 1992, was made for this health hazard evaluation (HHE). The purpose of the visit was to observe work practices, and conduct air, surface, and bulk sampling for lead.

BACKGROUND

Ohio University's pilot project to evaluate LBP cleaning methods took place in unoccupied buildings which were part of a former state residential hospital complex acquired from the State of Ohio. Ohio University planned to renovate the buildings, portions of which had been unoccupied and without utilities for many years. The buildings were three-story brick, built between 1873 and 1888, and contained many patient rooms of similar size which had painted plaster walls and ceilings, with terrazzo floors. Due to weathering, much of the paint which had been applied over the years was loose and peeling, and large amounts of paint chips and dust had fallen to the floors. Visual inspection revealed that some of the rooms had been painted many times with different colors, and possibly types, of paint. A previous building inspection conducted by university staff, with portable x-ray fluorescence (XRF) analyzers, had suggested that many of the walls, ceilings, and painted wood trim surfaces in the rooms were coated with LBP (range for apparent lead concentrations: <1 to 50 mg/cm^2). Previous sampling of the plaster walls and ceilings had not detected asbestos--a potential constituent of plaster in older buildings.

The university planned to clean gross lead contamination in the buildings, prior to future renovation work, to reduce the potential lead hazard for inspectors, architects and engineers who will need to enter the buildings. The LBP cleaning pilot project was designed to evaluate cleaning methods under consideration by the university. The three cleaning methods (and designations) used were:

- dry scraping followed by broom sweeping (dry sweeping)--This was selected to demonstrate exposures with no use of engineering or work practice controls.

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* As defined by Title X of the Housing and Community Development Act of 1992, Public Law 102-550, "the term `interim controls' means a set of measures designed to reduce temporarily human exposures or likely exposure to lead-based paint hazards, including specialized cleaning, repairs, maintenance, painting..."

- wet scraping (painted surfaces were wetted with water mist) followed by high-efficiency particulate air-filtered (HEPA) vacuuming (wet HEPA)

- wet scraping followed by HEPA vacuuming, with a HEPA-filtered air-filtration device (AFD) placed in the room to exhaust room air to the outside. The AFDs used were HEPA-AIRE® 2000, Model H2000C (Abatement Technologies, Duluth, GA). According to the manufacturer, these AFDs provide a maximum volume flow rate of 1550-1750 cubic feet per minute (cfm) with a clean filter, irrespective of the additional resistance provided by the 12-inch diameter flexible exhaust ducts which were used. The actual flow rates vary with the line voltage, and resistance to airflow at the inlets and outlets. These AFDs provided an estimated average of about 37 air changes per hour in the rooms cleaned.*

The final step for each of the above methods was wet-mopping of the floor (once) with fresh tri-sodium phosphate (TSP) detergent solution (mixed according to label directions), using a new string mop head for each room cleaned. The rooms' doors were kept open throughout the pilot project, except for brief periods when it was necessary to close them to clean around the door. AFDs were rolled between rooms on casters; they were not decontaminated between rooms.

An asbestos and lead abatement contractor (Lepi Enterprises, Inc., Zanesville, Ohio) agreed to donate labor for the pilot project to the university; however, the labor was limited to six workers for one day. The workers wore appropriate protective clothing, including safety glasses, disposable coveralls and boot covers, and NIOSH-approved half-face respirators with HEPA filter cartridges.

EVALUATION DESIGN AND METHODS

STUDY DESIGN

A previous NIOSH study of residential LBP abatement found that the geometric standard deviation (GSD) for PBZ lead exposures during various cleaning activities was 3.6.[1] NIOSH estimated that, assuming a GSD of 3.6 and three work crews, a total of 63 rooms would be required to detect a four-fold difference between geometric mean PBZ exposures for the three methods ($\alpha = 0.05$). Since a pilot project of this size was not feasible, the project was limited to 18 rooms, which was the estimated maximum number that could be cleaned with the available labor (six workers x one day).

Eighteen rooms, in two adjoining hospital buildings, were non-randomly selected for cleaning at the outset of the study, on April 29, 1992; the room locations are shown in Figure 1. To the extent possible, rooms of the same size with similarly deteriorated paint were selected. Most of the rooms were about 9 ft x 15 ft, with 12 ft (minimum height) ceilings; although some were larger, up to 14 ft x 22 ft. The workers were randomly assigned to three work crews of two workers each. Each work crew cleaned a total of six

* Assuming perfect mixing, an average AFD volume flow rate of 1000 cfm, and room volume of 9 x 15 x 12 ft (1620 ft^3), there were an average of 37 air changes per hour.

rooms; two rooms were cleaned consecutively with each of the three cleaning methods. The pilot project work crew assignments, and room sizes, are presented in Table 1. Each work crew's assignments, including chronological order for the three methods, and the rooms to be cleaned, were determined randomly.

ENVIRONMENTAL SAMPLING

The environmental lead sampling protocol conducted by NIOSH investigators during the three-day site investigation (April 29-May 1, 1992) is presented in Table 2. Pre-cleaning room and hall (floor) surface wipes, area air, and bulk paint chip samples were collected on the first day. PBZ and area air samples, and surface (hand lead) samples were collected during LBP cleaning on day two. Post-cleaning sampling, on the third day, repeated pre-cleaning sampling, except for bulk sampling.

Sampling and analytical methods used in this evaluation are summarized below. The NIOSH analytical methods referenced are described in the *NIOSH Manual of Analytical Methods, Third Edition*.[2] Each of the laboratory methods has a limit of detection (LOD) and limit of quantitation (LOQ), which are determined for each sample set in the laboratory. The minimum detectable concentration (MDC) and minimum quantifiable concentration (MQC) for a given air sample can be determined by dividing the LOD and LOQ, respectively, by an appropriate sample volume.

Bulk Samples:

Two samples (that appeared to be representative) of loose or peeling paint were collected in each room; from two different surfaces, usually a wall (or wood trim) and the ceiling. The paint chip samples (approximately 5 to 10 grams) were collected from surfaces with gloved hands and placed in sealable plastic food bags, for shipment to the laboratory. Bulk samples of paint chips were analyzed for lead and other elements according to NIOSH Method 7300. The LOQ for lead was 3 µg/sample.

Samples of wall plaster were collected from five randomly selected rooms. The samples were analyzed for percent and type asbestos with polarized light microscopy according to NIOSH Method 9002.

Surface Samples:

Floor surface lead concentrations were determined by wipe sampling 10 cm x 10 cm areas (defined by sampling templates) with individually wrapped towelettes (Wash'n Dri® , Softsoap Enterprises, Inc, Chaksa, MN) according to NIOSH Draft Method 0700--see Appendix A. These towelettes have been found to be free of lead contamination, and result in good analytical recovery for lead.[3] Disposable 10 cm x 10 cm sampling templates, cut from 8.5 x 11 inch plastic overhead transparency sheets, were used to avoid possible cross-contamination of samples. The disposable templates were held in place with masking tape on the outside edges during sampling, and a fresh template was used for each sample collected. Wipe samples were placed in sealable plastic food bags for shipment to the laboratory. The 10 cm x 10 cm areas that were sampled pre-cleaning were marked with a waterproof marker after sampling. Post-cleaning samples were collected near, but not on, the areas which had been previously sampled.

A brief study was conducted in an effort to estimate the sample variability of surface wipe samples collected using this method. Sets of five adjacent (in a row) wipe samples (10 cm x 10 cm areas, as described above) were collected on the terrazzo floors, near the room center, in three randomly selected rooms, both pre- and post-cleaning.

Pre- and post-handwashing hand lead concentrations were measured by collecting samples immediately before and after handwashing, at the lunch break and the end of the shift. Handwashing was accomplished with hand soap, running water, and disposable towels at a staging area in one of the buildings being cleaned. The sampling procedure was to give each worker an individually-wrapped towelette, have the worker open the towelette package, wipe both hands thoroughly with it for a timed 30-sec period, and then place the towelette in a sealable, heavyweight plastic food bag. Samples were analyzed by NIOSH Method 7105 (lead by graphite furnace atomic absorptions spectrometry [AAS]), modified for sample matrix as per NIOSH Draft Method 0700. The LODs and

LOQs for lead were 0.09-5 µg/wipe and 0.31-15 µg/wipe, respectively, depending on dilution during sample preparation.

Air Samples:

PBZ and area samples were collected with personal sampling pumps at a flow rate of 2.0 L/min; the pumps were calibrated immediately before and after sampling with a mass flowmeter which had been calibrated with a primary standard (bubble flowmeter). The means of the measured pre- and post-sampling flow rates were used to calculate sample volumes. PBZ samples were collected in workers' breathing zones by attaching the media on the workers' shirt collars. Samples were analyzed according to NIOSH Method 7105 (lead by graphite furnace AAS). The LOD and LOQ were 0.08 and 0.28 µg/sample, respectively.

DATA ANALYSES

The primary outcomes of interest were the PBZ and area airborne lead concentrations, and the change (post- minus pre-cleaning) in floor surface lead concentrations in the rooms and hallways. The analyses (ANCOVAs) which were performed with the data are presented in Table 3. Due to the relatively small sample size, the analyses did not include consideration of potential interactions between independent variables.

EVALUATION CRITERIA

GENERAL

As a guide to the evaluation of exposures to chemical and physical agents in the workplace, NIOSH employs criteria which are intended to suggest levels of airborne exposure to which most workers may be exposed up to 10 hours per day, 40 hours per 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 below the evaluation criteria. Some substances are absorbed by direct contact with the skin and mucous membranes, or by ingestion, and thus the overall exposure may be increased above measured airborne concentrations. Evaluation criteria change over time as new information on the toxic effects of an agent becomes available.

The primary sources of evaluation criteria for the workplace are: NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[4] the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs),[5] and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[6] Employers are required to comply with the OSHA PELs, and other OSHA standards.

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-hour (PEL-TWAs, TLV-TWAs) or up to 10-hour (REL-TWAs) workday. Concentrations are usually expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), micrograms per cubic meter ($\mu g/m^3$), or fibers per cubic centimeter ($fibers/cm^3$). To compare results with the NIOSH REL-TWAs and OSHA PEL-TWAs, it is sometimes useful to extrapolate an equivalent 8-hr TWA exposure for sampling times of shorter than 8-hr duration. In extrapolating an 8-hr TWA, an assumption is made that there was no other exposure to the compound of interest over the remainder of the 8-hr work-shift.

LEAD

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 initially in the liver and kidneys.[7] Lead 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 acute lead intoxication include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort, colic, anemia, high blood pressure, irritability or anxiety, fine tremors, pigmentation on the gums ("lead line"), and "wrist drop."[8,9,10]

Overt symptoms of lead poisoning in adults generally begin at BLLs between 60 and 120 micrograms per deciliter (µg/dl). 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.[11] The mean serum lead level for U.S. men from 1976-1980 was 16 µg/dl.[12,13] However, with the implementation of lead-free gasoline and reduced lead in food, it was estimated that the 1991 average serum lead level of U.S. dropped below 9 µg/dl.[14]

Under the OSHA standard regulating occupational exposure to inorganic lead in general industry, the PEL is 50 µg/m^3 as an 8-hour TWA.[15] The standard requires semi-annual monitoring of BLL for employees exposed to airborne lead at or above the Action Level of 30 µg/m^3 (8-hour TWA), specifies medical removal of employees whose average BLL is 50 µg/dl or greater, and provides economic protection for medically removed workers. The construction industry was exempted from this regulation when it was promulgated in 1978. NIOSH is presently reviewing literature on the health effects of lead to revise its REL.

Recent studies suggest that there are adverse health effects at BLLs below the current evaluation criteria for 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 threshold through less than 10 µg/dl. 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, birthweight, and early mental development at prenatal maternal BLLs as low as 10 to 15 µg/dl.[16]

In recognition of the health risks associated with exposure to lead, a goal for reducing occupational exposure was 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.[17]

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.[18] 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.

NIOSH and OSHA have recently published recommendations for construction workers potentially exposed to lead.[19,20] 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 monitoring, notification, and medical removal protection specified in the OSHA general industry lead standard should be applied to construction workers, except that more frequent monitoring (for example, monthly) may be necessary. 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).

Lead in Surface Dust:

There are no Federal standards governing the level of lead in surface dust in either occupational or non-occupational (i.e., residential) settings. However, lead-contaminated surface dust in either setting represents a potential exposure to lead through ingestion, especially by children. This may occur either by direct hand-to-mouth contact with the dust, or indirectly from hand-to-mouth contact via clothing, food, and other objects that are contaminated by lead dust. Previous studies have found a significant correlation between resident childrens' BLLs and house dust lead levels.[21] Based on previous standards established in Massachusetts and Maryland, the U.S. Department of Housing and Urban Development (HUD) has recommended the following final clearance standards for lead in house dust on specific interior surfaces following lead abatement:[22] floors, 200 micrograms per square foot (µg/ft^2); window sills, 500 µg/ft^2, and window wells, 800 µg/ft^2. These criteria were not based on epidemiology, but were empirically established as feasible limits for clearance following final cleaning during residential lead-based paint abatement. HUD recommends the use of these criteria until they are refined or replaced through additional research.

RESULTS AND DISCUSSION

GENERAL

Bulk Samples:

The overall mean paint lead concentration was 4.3% (n=36), see Table 4. Paint lead concentrations varied widely, the overall relative standard deviation (RSD)* was 184%. Nine of the 18 rooms selected for cleaning had mean paint lead concentration greater than the federal LBP criteria of 0.5 % lead by weight (range: 2.8% - 19%), as defined under

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*RSD% = (standard deviation/mean) x 100%

Section 302 of the Lead-Based Paint Poisoning Prevention Act (42 USC* 4822). In four of these nine rooms, both paint samples were LBP (>0.5% lead), in the other five only one sample was LBP, and in the remaining nine rooms neither paint sample was LBP. Although rooms were assigned randomly to each of the three methods, paint lead concentrations may have differed among the methods. Of the six rooms assigned to each method, one of the rooms for dry sweeping , three of the rooms for wet HEPA, and five of the rooms for wet HEPA/AFD had a mean paint lead >0.5%; see Table 5. To account for these differences in data analyses, covariates (per room) were adjusted for mean paint lead concentrations (see Data Analyses section below). It should be noted that since only two paint samples per room were collected, the mean paint lead concentrations may not have been representative of all surfaces cleaned.

No asbestos was detected in five samples of plaster collected from walls in five randomly selected rooms.

*_United States Code_.

Surface Samples:

Room surface lead concentrations were measured on the floor near the center of each room, see results in Figure 2 and Table 5. Pre-cleaning, the rooms had a mean (floor) surface lead concentration of 2600 µg/ft^2 (range: 620 - 8200 µg/ft^2) indicating gross lead contamination, in spite of the fact that an attempt was made to exclude areas with visible paint chips during sampling. Overall, the post-cleaning room surface lead concentrations were significantly reduced, mean 1300 µg/ft^2 (range: 250 - 4200 µg/ft^2), p=0.018, Wilcoxon signed ranks test. All 18 post-cleaning room surface lead concentrations exceeded the HUD residential surface lead clearance criteria of 200 µg/ft^2 for floors. This result was not unexpected, because meeting the HUD criteria was not a goal of the cleaning. Also, the more extensive containment and final cleaning procedures that have been recommended by HUD for residential LBP abatement[22] were not followed in the pilot project. The changes in room surface lead concentration (post- minus pre-cleaning) among the 18 rooms varied widely; surface lead concentrations decreased in 14 rooms (range: -6690 to -110 µg/ft^2), there was no change in one room, and in three rooms surface lead concentrations appeared to increase (range: 600 to 2000 µg/ft^2), see Figure 2. The floor surfaces which were sampled visually appeared to be less contaminated with paint chips and dust after cleaning, so it is likely that the post-cleaning surface lead consisted of primarily of small particles not removed by the cleaning. Additionally, the apparent increases may have been due to the high variability of adjacent surface samples (see below).

The pre-cleaning hall (two feet outside room doors) surface lead concentrations, with an overall mean of 4049 µg/ft^2 (range: 930 - 10,000 µg/ft^2), were generally even higher than that of the rooms, see Table 5. Overall the post-cleaning hall surface lead concentrations, mean 5483 µg/ft^2 (range: 1000 - 20,000 µg/ft^2) did not differ significantly from the pre-cleaning concentrations, p=0.35, Wilcoxon signed ranks test. It should be noted that cleaning the hallways was not an objective of the pilot project, although in many cases the HEPA vacuuming and mopping was extended at least two feet outside the rooms. The change in all surface lead concentration (post- minus pre-cleaning) ranged from -5,800 to 20,000 µg/ft^2, and was an increase in lead contamination for 12 of the 18 hall areas. It is likely that increases were due to lead contamination which was tracked out by workers, carried out on equipment, and, to a lesser extent, fugitive airborne lead (hall area airborne lead levels during cleaning were relatively low--see Area Air Sampling below).

The results of the study of surface sample variability (five adjacent wipes collected in six rooms) are presented in Table 6. It can be seen from the data of Table 6 that the field sample variability is quite high. In some rooms, the quantities of dust or paint chips on adjacent surface areas sampled were visually non-uniform. Variability of adjacent surface samples, as measured by the RSD, was 46% to 69% in the three rooms which were sampled pre-cleaning, and 17% to 48% in three rooms sampled post-cleaning. One set of post-cleaning wipe samples revealed rather low sample variability (RSD = 17%, Table 6). This may be due in part to the relatively low lead levels in this sample set. Of course, there are other contributions to the variability of field samples (e.g., type of substrate surface, individual variations in sampling technique, etc.), but these sources of variability are difficult to eliminate. In all 18 rooms, a single surface sample (non-adjacent) was also collected, see Table 6. In all six rooms where adjacent wipe samples were collected, the result for the single surface sample (also reported in Table 5) was within the range of the adjacent sample results. Results of single pre- and post-cleaning surface samples were used in the data analyses.

The results of sampling for hand lead pre- and post-handwashing are presented in Table 7. All six workers were sampled at the lunch break and again at the end of the shift. Hand lead levels at the lunch break were quite variable, both pre-handwashing (mean 703 µg, RSD = 74%) and post-handwashing (mean: 55 µg, RSD = 74%); similar results were found at the end of the shift. However, for all six workers, measured hand lead levels were markedly reduced by handwashing with soap and water.

Area Air Sampling:

Results for general area airborne lead concentrations are presented in Table 8. Airborne lead concentrations were 1.6 and 3.8 µg/m^3 in the building during pre-cleaning bulk and surface wipe sample collection (day 1); and slightly lower, 1.1 and 0.60 µg/m^3, respectively, at the same locations during post-cleaning surface sample collection (day 3). During LBP cleaning activities (day 2) general area lead concentrations on the two affected floors in the building were somewhat higher, 3.1 and 4.6 µg/m^3. Airborne lead concentrations measured in an unaffected area outside the building were 0.095 µg/m^3 and none detected,* on days 2 and 3, respectively. Since the building hallways were grossly contaminated with lead, and only small portions of the halls were cleaned, it is likely that the source of airborne lead measured in the building during pre- and post-cleaning (days 1 and 3) was lead-containing dust on the hall floors which was stirred up by occupant and equipment movement. On the actual day of cleaning, somewhat higher area airborne lead levels were probably due to the higher activity level in the halls and by fugitive dust from LBP cleaning activities in the rooms.

During cleaning, the mean for short-term (13-55 min) area airborne lead concentrations measured inside rooms was 44 µg/m^3 (range: 4.1 - 180 µg/m^3); see Tables 5 and 8. Ten of 18 room area concentrations exceeded the OSHA Action Level of 30 µg/m^3; six of six for dry sweeping method, one of six for wet HEPA method, and three of six for wet HEPA/AFD method.

The mean hall area lead concentration, for six areas immediately outside rooms during cleaning, was 12 µg/m^3 (range: 1.9 - 18 µg/m^3). Both the highest and lowest hall concentrations measured were for rooms cleaned with the wet HEPA/AFD method. Unlike the other five hall area measurements, one hall measurement for wet HEPA/AFD (18 µg/m^3) was greater than the corresponding room area measurement (8.6 µg/m^3), which suggests that it may have been due to entrainment of emissions from another nearby room. The results indicated that airborne lead was released to surroundings during all three cleaning methods, although all hall concentrations were relatively low, below the OSHA general industry Action Level of 30 µg/m^3. Further study is needed to determine the effectiveness of general exhaust ventilation with AFDs in reducing fugitive airborne lead emissions during LBP cleaning and abatement.

PBZ Air Sampling:

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* Less than the MDC of 0.4 µg/m^3, for 188 L sample volume.

The overall mean for short-term (13 - 55 min) PBZ airborne lead exposures inside rooms during cleaning was 66 µg/m^3 (range: 5.0 - 360 µg/m^3), see Tables 5 and 8. The results indicated the potential for worker overexposures during all three LBP cleaning methods. Sixteen of 36 short-term PBZ exposures equalled or exceeded 50 µg/m^3; 9 of 12 for dry sweeping, one of 12 for wet HEPA, and six of 12 for wet HEPA/AFD.

Short-term lead exposures (per room) among the 2-man work crews were reasonably well correlated overall (r^2=0.59), see Figure 3. The average of the two PBZ exposures (per room) was used as a variable (see Data Analyses section below). Short-term area lead concentrations were well correlated with the mean PBZ exposures (r^2=0.72), see Figure 4.

The range for five long-term (approximately 5 hours) PBZ lead exposures measured on the day of cleaning was 9.4 to 110 µg/m^3, see Table 9. Because the sampling periods were less than a full 8-hr shift (sampling did not include a lunch break and some setup), 8-hr TWAs were extrapolated by assuming no other airborne lead exposure during the workshift. Since that assumption was not always valid, the extrapolated 8-hr TWAs reported should be considered minimum values. One of the five extrapolated 8-hr TWAs exceeded the OSHA PEL-TWA of 50 µg/m^3 (range: 6 - 73 µg/m^3). The 8-hr TWA exposures among the two workers on crew 2 (who cleaned the same rooms) were quite different, 24 µg/m^3 and 73 µg/m^3. This result is primarily due to exposures in one of the six rooms the crew cleaned (room 9), where the workers' short-term (55 min) PBZ exposures were 110 and 360 µg/m^3, respectively, see Table 8, page 2. The differences indicate that individual work practices are an important determinant of lead exposures during LBP cleaning.

DATA ANALYSES

The parameters for each of the four analyses presented below are presented in Table 3. Overall, the variability of PBZ exposures measured during this project (GSD = 2.9) was less than what was expected, based on the results for LBP cleaning activities in a previous NIOSH study of lead abatement workers (GSD = 3.6)[1]. The previous study included far more workers, abatement contractors, and structures over a much longer time period. Accordingly, although the pilot project size was limited to cleaning 18 rooms, the statistical power of this project was greater than expected.

ANCOVA 1:

Overall, the method, mean paint lead concentration, pre-cleaning surface lead concentration, and crew were jointly significantly associated with observed variation in mean PBZ lead exposures, p=0.023, df* 6, 11. Both method and crew variables, after adjusting for the other variables in the model, were borderline significant, p=0.056 and 0.054, respectively. The adjusted (least squares) mean PBZ exposure for dry sweeping (107 µg/m^3) was significantly greater than that for wet HEPA (34 µg/m^3) p=0.021, but not wet HEPA/AFD (56 µg/m^3), p=0.095. The use of AFDs in rooms (with an estimated average of 37 air changes per hour), which was expected to lower workers lead exposures, did not provide any measurable benefit, and may have increased exposures.

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*degrees of freedom.

This may be because use of the AFDs in the relatively small rooms actually stirred up dust, either with air turbulence created by the exhaust, or because it was necessary to move them frequently during cleaning. The adjusted (least squares) mean PBZ exposure for crew 3 (14 µg/m^3) was significantly lower than either of those for crews 1 and 2, which did not differ significantly (103 and 81 µg/m^3), p=0.026 and 0.045, respectively. The measured difference between crews indicates that work practices are an important determinant of personal exposures.

It has been suggested that renovators test surfaces for LBP in older housing as a means to determine the potential for personal lead overexposures during various renovation and demolition activities.[23] However, the correlation between mean paint lead concentrations and mean PBZ exposures overall was very weak (r^2=0.13), as were the corresponding correlations by method: dry sweeping (r^2=0.33), wet HEPA (r^2=0.013), and wet HEPA/AFD (r^2=0.15), see Figure 5. In fact, the mean PBZ exposure was greater than 50 µg/m^3 in four of the nine rooms with mean paint lead concentrations below 0.5%. The results should be interpreted with caution due to small sample sizes, and may be, at least in part, because paint sampling was not representative of all surfaces with LBP--only two paint samples per room were collected.

However, the results are consistent with the finding in this study that PBZ exposures are dependent on several variables, in addition to the mean paint lead concentrations. This finding is also supported by a previous NIOSH study of lead abatement workers, in which testing for LBP was comprehensive, which also found a very weak overall correlation between mean paint lead and (log) mean airborne lead concentrations (r^2=0.175)[1] .

ANCOVA 2:

Overall, the method, mean paint lead concentration, pre-cleaning surface lead concentration, and crew were jointly significantly associated with observed variation in area airborne lead, p=0.015, df 6, 11. The method variable, after adjusting for the other variables in the model, was significant, p=0.016. The adjusted (least squares) mean area concentration for dry sweeping (80 µg/m^3) was significantly higher than those for either wet HEPA (26 µg/m^3) and wet HEPA/AFD (25 µg/m^3), p=0.011 for both, and the latter two methods did not differ significantly. The use of AFDs in rooms (with an estimated average of 37 air changes per hour), which was expected to lower room airborne lead concentrations, did not provide any measurable benefit. This may be because use of the AFDs in the relatively small rooms actually stirred up dust, either with air turbulence created by the exhaust, or because it was necessary to move them frequently during cleaning. The crew variable, after adjusting (least squares means) for other variables, was not significant, p=0.10 .

ANCOVA 3:

Overall, the method, mean area airborne lead concentration, mean paint lead concentration, pre-cleaning surface lead concentration, and crew were not jointly significantly associated with observed variation in (log) room post-cleaning surface lead concentrations, p=0.13, df 7, 10. The adjusted (least squares) means for dry sweeping (250 µg/ft^2), wet HEPA (1500 µg/ft^2) and wet HEPA/AFD (2100 µg/ft^2) did not differ significantly, p=0.15, due in large part to the amount of variability observed.

ANCOVA 4:

Overall, the method, mean area airborne lead concentration, mean paint lead concentration, pre-cleaning surface lead concentration, and crew) were not jointly significantly associated with observed variation in (log) hall post-cleaning surface lead concentrations, $p=0.48$. The adjusted (least squares) means for dry sweeping (2800 µg/ft^2), wet HEPA (4700 µg/ft^2) and wet HEPA/AFD (9100 µg/ft^2) did not differ significantly, $p=0.24$, due in large part to the amount of variability observed.

CONCLUSIONS

- Workers are potentially overexposed to lead during all of the LBP cleaning activities evaluated: dry sweeping, wet HEPA, and wet HEPA/AFD.

- PBZ and area airborne lead concentrations during LBP cleaning are dependent on several variables, including the method, mean paint lead concentration, pre-cleaning surface lead concentration, and crew. The mean paint lead concentrations (obtained from sampling two surfaces per room) were a poor predictor of personal exposures during cleaning, as high airborne lead exposures occurred even in rooms with low (<0.5%) mean paint lead concentrations.

- Of the three cleaning methods evaluated (after adjusting for other variables), the wet HEPA method appeared to offer the best control for worker lead exposures, and room airborne lead concentrations.

- The significant differences between mean PBZ exposures among work crews, and between workers on a single crew, indicate that individual work practices are an important determinant for personal lead exposures during LBP cleaning activities.

- The use of air filtration devices (AFDs) in the rooms with the wet HEPA method did not provide any additional reduction of worker lead exposures or area lead concentrations; and may have, in some cases, increased personal lead exposures.

- Overall, room surface lead concentrations were significantly reduced by the LBP cleaning; the cleaning effectiveness of the three methods, as measured by the change in room surface lead concentrations, did not differ significantly.

- Overall, hall surface lead concentrations were not significantly increased by the LBP cleaning, although there was an apparent increase outside some of the rooms. The effectiveness of the three methods, as measured by change in hall surface lead concentrations, did not differ significantly.

- Post-cleaning surface lead concentrations indicated that all of the rooms were still contaminated with lead dust. Better containment of dust and debris, and/or repeated vacuuming and mopping, would be necessary to meet the HUD final clearance criteria of 200 µg/ft^2 for (residential) floor surfaces.

- Bulk sampling of plaster did not indicate a potential for asbestos exposure during LBP cleaning at this facility.
- The variability of lead concentrations among bulk paint samples from different component surfaces, and adjacent floor surface samples, even within rooms was quite high.
- Worker hand lead concentrations were markedly reduced by handwashing on-site with soap, running water, and disposable towels.

RECOMMENDATIONS

In general, the recommendations for air monitoring, engineering controls, personal hygiene practices, personal protective equipment, and medical surveillance contained in the NIOSH *Alert-Preventing Lead Poisoning in Construction Workers* [20] should be applied to LBP cleaning. The following specific recommendations are offered to reduce worker lead exposures during future LBP cleaning.

1. Of the three LBP cleaning methods evaluated, the wet HEPA method is recommended as the best control for worker lead exposures. However, even using this method, lead exposures during cleaning reached 50 µg/m^3.

2. The contractor should continue to provide workers with NIOSH-approved HEPA-filtered respirators, in the context of a respiratory protection program meeting OSHA requirements (29 CFR 1910.134); protective clothing, a clean clothes changing area, handwashing facilities, and job-specific hazard training during future LBP cleaning in the buildings (with any of the three methods).

3. With regard to planning future cleaning in the buildings, the University should either assume all rooms in the buildings evaluated contain LBP, or conduct a more thorough LBP inspection of all areas to be cleaned. For future LBP inspections, the testing and inspection procedure that has been recommended by HUD[22] for public housing should be used.*

4. Since all of the post-cleaning floor surface concentrations were above the HUD-recommended residential final clearance level, the University should perform additional final cleaning, such as the final cleaning recommended by HUD[22], in the buildings prior to occupancy. Due to the continuing deterioration of existing paint, plaster walls, and ceilings, it may not be worthwhile to do the final cleaning until after all the renovation work is completed.

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* NIOSH investigators recommend laboratory testing for the quantitative determination of paint lead concentrations.

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Appendix A
Lead in Surface Wipe Samples

NIOSH Draft Method 0700
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