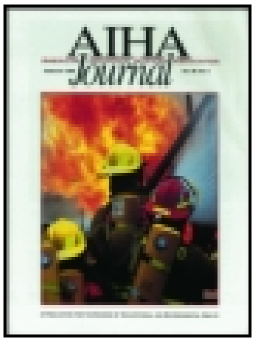

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John C. Johnson , Stephen J. Reynolds , Laurence J. Fuortes & William R. Clarke

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AUTHORS
John C. Johnson[a]*
Stephen J. Reynolds[a]
Laurence J. Fuortes[a]
William R. Clarke[b]

[a]Division of Occupational and Environmental Health, Department of Preventive Medicine, University of Iowa, Iowa City, IA 52242;
[b]Division of Biostatistics, Department of Preventive Medicine, University of Iowa, Iowa City, IA 52242;
*Current address: Environmental Health Systems, 1356 Shannon Dr., Iowa City, IA 52246; e-mail: ehs9535@iowaemail.com

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Airborne and surface lead exposures were evaluated for construction trade groups at a previously deleaded bridge renovation site in the midwestern United States. Although all lead-based paint should have been removed, old layers of leaded paint were still present on some sections of the bridge. Ironworkers performing metal torch cutting had the highest exposures (188 μg/m^3), followed by workers engaged in clean-up operations and paint removal ($p < 0.001$). Respirators were most frequently worn by workers with the greatest lead exposures; however, laborers performing clean-up operations had exposures to lead dust of 43 μg/m^3 and often wore no respiratory protection. Wipe samples revealed that almost all contractor vehicles were contaminated with lead. Heavy equipment operators with low airborne lead exposure had the highest levels of surface contamination in personal vehicles (3600 μg/m^2). Laborers cleaning structural steel with compressed air and ironworkers exposed to lead fumes from cutting had the highest concentrations of lead dust on clothing (mean 4766 μg/m^2). Hand-washing facilities were provided, but were infrequently used. No separate clothes changing facility was available at the site. The potential for "take-home" contamination was high, even though this site was thought to be relatively free of lead. Construction contractors and their workers need to be aware that previous deleading of a site may not preclude exposure to significant amounts of lead.

Keywords: bridge renovation, construction work, lead exposure

APPLIED STUDIES

Lead has been used in a variety of industrial products, including paints, gasoline, and water pipe. Until recently, lead-based paints were the coatings of choice for corrosion protection on exposed metal surfaces; residues of these lead coatings are still present on many bridges, storage tanks, and other structural metals.(1) Exposure to lead is now recognized as a primary health hazard for construction workers. It has been estimated that nearly 1 million construction workers per year in the United States are occupationally exposed to lead, and, of these, over 50,000 are engaged in structural steel rehabilitation and repainting. Of particular concern are those activities that involve the demolition, repair, and reconditioning of lead-based painted surfaces, such as bridge renovation work, which can generate significant airborne lead concentrations.(2–11) Tasks such as abrasive blasting, welding, and torch cutting of surfaces coated with lead-based paints have high risk of lead exposure, due to the generation of lead dusts and fumes. Airborne lead concentrations at bridge repair sites have been reported to be as high as 29,400 μg/m^3.(10) Without appropriate control measures in place, these construction workers face the potential for significant exposure to lead. Indirect exposure of co-workers and family members also has been reported, as lead may be carried home on workers' clothes, skin, and in personal automobiles.(12–14) Workers at sites that have been previously deleaded may still be at risk from exposure to lead that was left behind in inaccessible locations.(15)

BACKGROUND

A multispan steel girder highway bridge in the midwestern United States underwent renovation during parts of 1995 and 1996. These operations involved the demolition, removal, and replacement of concrete roadway and portions of structural metal. It was reported that lead-based paint had been removed from the bridge by sandblasting several years before, and that metal surfaces had been repainted with a lead-free paint. This was found not to be the case: lead contamination arose from disturbance of old layers of leaded paint coatings on relatively inaccessible structural metal. Due to inaccessibility, and the consequent difficulty of removal, this paint had not been eliminated during the previous deleading and repainting operations. Within 1 month after beginning renovation, several workers complained of symptoms, including headache, stomach pain, irritability, and muscle aches. Lead poisoning was diagnosed in one worker, and thereafter a medical and industrial hygiene intervention was initiated, including development of a lead exposure compliance program.[15]

This study was undertaken to evaluate lead exposures among the workers renovating this previously deleaded bridge. Its objectives were to evaluate the distributions of airborne and surface lead concentrations; to compare exposures among various trade groups and between tasks; to identify work tasks with the highest risk for overexposure to lead; and to evaluate the use and effectiveness of personal protective equipment and engineering controls in reducing lead exposure. Blood lead determinations were not included as part of the study. Several of the workers monitored here for air and surface lead exposure did participate in a concurrent study of construction worker blood lead levels in the Midwest region.[16]

Trades/Tasks Involved in Bridge Renovation

Construction trade groups included metal cutter/ironworker, laborer, equipment operator, observer, and painter. Tasks performed included torch cutting on structural metal; demolition of concrete roadbed, including removal of debris by compressed air cleaning; operation of heavy machinery/equipment; finishing operations, such as cement pouring and carpentry work; and paint removal and repainting inside a partially enclosed containment. The observer category included supervisory and managerial personnel.

METHODS

Data Collection/Field Sampling

Air and wipe samples were collected from April to July 1996. Personal samples were collected from randomly selected workers within each task. Personal breathing zone samples were collected for 22 individuals on 43 occasions. Area air samples also were collected to characterize general environmental concentrations of airborne lead. Air samples were collected on 37-mm mixed cellulose ester filters using personal sampling pumps (e.g., SKC AIR-CHEK, SKC Inc., Eighty Four, PA) calibrated at a flow rate of approximately 2 L/min as specified in NIOSH standard methods.[17] Field and laboratory blanks were used for quality control of sample collection. Air samplers were worn by workers for the duration of their specific tasks, with sampling filters located in the workers' breathing zones. When it was not possible to obtain a full 8-hour sample, partial-shift samples were collected. Each personal sample represented one task performed over that shift. Observations on work activities and use of personal protective equipment and engineering controls were documented.

TABLE I. Eight-hour TWA Lead Concentrations by Trade/Task at Midwest Bridge Renovation Site

Trade/Task	N	Mean (μg/m^3)	Range	SD	No. Times TWA > PEL
Ironworker[A] (metal cutting)	11	192.7	1.1–512	175.5	8
Laborer[A] (demolition)	5	43.4	10.3–93.6	43.2	2
Equipment oper.[A] (demolition)	3	14.3	1.8–28.2	13.3	0
Observer	5	1.1	0.91–1.58	0.23	0
Carpenter[A] (deckforming)	9	2.2	0.9–3.3	0.70	0
Painter (paint removal)	4	93.7	62.6–130.8	29.0	4
Area samples	4	9.2	1.14–19.5	7.6	0

[A]$p < 0.05$.

Wipe samples were collected from workers' clothing and from vehicles used by the bridge renovation contractor. Sampling methodology followed Occupational Safety and Health Administration (OSHA) specifications for surface wipe sampling, using Whatman #42 filter paper sampling over a 100 cm^2 area (10 cm × 10 cm).[18] Filter papers were then placed inside resealable plastic vials for shipment to the laboratory. Thirteen wipe samples were taken of dust from worker clothing, and 24 samples were taken of surface dust inside contractor vehicles and equipment, not including field and laboratory blanks.

Chemical analysis of samples by flame atomic absorption spectroscopy (AAS) was conducted by an American Industrial Hygiene Association-accredited laboratory, following Environmental Protection Agency (EPA) method 239.1 for air and EPA method 7420 for wipe samples.[19] Air concentrations were reported as micrograms per cubic meter; wipe sample concentrations were calculated as micrograms per square meter of sampled area. All blanks submitted for analysis were below detectable levels for flame AAS.

Data Analysis

Statistical analysis was performed using SPSS version 6.1 (SPSS Inc., Chicago, Ill.). Descriptive statistics were used to evaluate distributions and test for normality of data. Sampling data were not normally distributed; log transformation of data also did not result in a normal distribution. Therefore, nonparametric procedures were used to test for differences in lead exposure among trade groups and between workers using and not using respirators. Kruskal-Wallis one-way nonparametric analysis of variance was used to test for differences in lead concentrations among trade groups. Pairwise comparisons were conducted using Wilcoxon rank sum tests. Job tasks were closely associated with trade group as listed in Table I; however, laborers and equipment operator categories were combined in "demolition" work, and carpenters/concrete finishers combined as "deckforming." Before comparing results among trades and work tasks, repeated samples taken on individual workers were averaged. This average value was used in the comparative analyses.

RESULTS

Air Sampling

Forty-one personal air samples, representing a total of 22 individuals, were analyzed for lead. Samples were identified by randomly

TABLE II. Airborne Lead Concentrations, Engineering Controls, and Respirator Use at Midwest Bridge Renovation Site

Controls Used	N	TWA ($\mu g/m^3$)	Range	SD	No. Times TWA > PEL
None	22	9.0	0.9–93.6	18.2	1
Respirator only	8	226.2	76.0–512	182.4	7
Eng. control + resp.	7	109.2	1.1–250	77.3	6

assigned identification number, then grouped by trade, task performed, personal respirator use, and engineering controls present at the work site. Overall mean lead concentration was 88.1 $\mu g/m^3$ (range 0.9–512). Metal torch cutting had the highest mean concentration at 192.7 $\mu g/m^3$ (range 1.1–512). Paint removal operations had the next highest mean concentration of 93.7 $\mu g/m^3$ (range 62.6–130.8). Eight-hour time-weighted average (TWA) exposures were calculated to determine compliance with the current OSHA permissible exposure limit (PEL) for lead of 50 $\mu g/m^3$ (see Table I) No exposure was assumed to occur during lunch or break periods. Kruskal-Wallis one-way analysis of variance rank sums for comparison of airborne lead concentrations among trades confirmed that ironworkers had the highest TWA (188 $\mu g/m^3$), painters were second, and laborers were third highest ($p < 0.001$).

Data were further analyzed by averaging individual air sampling results. Twenty-one TWA concentrations were analyzed for statistically significant differences among trade groups and work tasks. Wilcoxon rank sum, which calculates rank order differences between variables, was used as a nonparametric alternative to the paired t-test. These results revealed that torch cutting and other demolition work had significantly higher ($p < 0.05$) airborne lead exposure than either carpentry or finishing operations.

The Mann-Whitney U test was used to evaluate differences in airborne lead concentrations among those workers who did or did not use respirators during work, and to determine whether the presence of engineering controls (ventilation) at the work site had any effect on measured airborne concentration (Table II). Engineering controls were more often present at higher airborne lead concentrations ($p = 0.027$), and respirator use was also more prevalent among those workers having higher TWA concentrations ($p < 0.001$).

Surface Wipe Sampling

Dust sampling indicated that laborers performing demolition work had the highest concentration of lead (mean 4766 $\mu g/m^2$) on clothing (Table III). This may be due to the large amounts of dust generated by the use of compressed air in cleaning steel beams. All contractor vehicles sampled showed some presence of lead contamination. Control knobs and cab floors of heavy machinery were highly contaminated (mean 3145 $\mu g/m^2$). The equipment operator's personal vehicle was also contaminated with lead on the steering wheel and floor (3600 $\mu g/m^2$).

TABLE III. Results of Wipe Sampling among Construction Trades at Midwest Bridge Renovation Site

Trade	N	Mean ($\mu g/m^2$)	Range	SD
On clothing				
Ironworker	8	2081.3	250–4400	1563
Laborer	3	4766.7	4200–6500	1531
Observer	2	250.0	250–250	0
In vehicles				
Ironworker	6	750.5	119–2500	947
Laborer	3	1735.3	250–3600	1707
Equipment oper.	7	3144.9	250–9000	3485
Observer	8	433.9	171–1800	553

Personal Protective Equipment and Engineering Controls

Personal protective equipment worn by workers at this Midwest bridge renovation consisted of coveralls, gloves, and, for torch cutting operations, a half-mask respirator with particulate filter; no other type of respiratory protection was worn by those workers with the highest lead exposure. Laborers cleaning metal beams with compressed air sometimes wore no respiratory protection; at other times a half-mask was used. Painters working inside the containment structure were also observed to wear half-mask respirators with particulate filters. Fans were used during torch cutting to blow fumes and dusts away from workers' breathing zones. It was observed that these were seldom used effectively, and generally blew potential contaminants into the breathing zone rather than away from it. Atmospheric conditions such as wind speed and direction were highly variable, and renovation activities could not be relocated to take advantage of favorable natural ventilation.

DISCUSSION

Results of Previous Research on Bridge Renovation Work

Goldberg et al.[20] employed a task-based method of lead exposure assessment among ironworkers at a bridge rehabilitation site in New York City. Tasks such as torch cutting, scaling, rivet busting, and grinding were identified, and workers were monitored while performing these tasks. Lead concentrations recorded during torch cutting ranged from 63–5134 $\mu g/m^3$, scaling and grinding from 28–5509 $\mu g/m^3$, and rivet busting from 10–1200 $\mu g/m^3$. Mean sampling times ranged from 75–315 min, depending on the task being performed. The authors suggested that this type of sampling strategy yields more realistic exposure monitoring results than the standard TWAs for an 8-hour shift. Waller,[21] in investigating lead exposure during a storage tank demolition, recorded airborne lead concentrations between 684–11,000 $\mu g/m^3$ during metal cutting. The mean 8-hour TWA was 2051 $\mu g/m^3$ for metal cutters. Lead content of the painted metal was estimated at 10% dryweight. After a work site intervention to reduce lead exposure, the TWA for metal cutting was reduced to 838 $\mu g/m^3$. Spee and Zwennis[22] recorded lead concentrations in the breathing zone of five workers during the demolition of a lead-painted steel bridge. The bridge had been coated several times previously with a primer containing up to 60% lead dryweight. Concentrations recorded during torch cutting of the structural metal ranged from 2300–32,000 $\mu g/m^3$. Sussell et al.[10] reported on a cohort of bridge workers exposed to high levels of airborne lead. Concentrations were noted as high as 29,400 $\mu g/m^3$ for abrasive blasters and from 5–6720 $\mu g/m^3$ for other trade groups.

Piacitelli et al.[13,14] reported lead dust concentrations of 240–2000 $\mu g/m^2$ in workers' automobiles at a bridge renovation site in Connecticut. The highest levels were found in the automobiles of workers not exposed to the highest concentrations of lead dust in the workplace, that is, occupational safety and health personnel and security guards. Piacitelli et al. (1995) attributed this discrepancy to the fact that abrasive blasters, who were potentially exposed to very high levels of lead, changed their clothes after work, and thus had less possibility for "take home" exposure. Piacitelli et al. (1997) reported that contamination of lead-exposed workers' automobiles was up to 10 times that of controls. Highest lead levels were found on driver's floor and armrest. The authors reported that employers and workers rarely followed measures intended to reduce this take-home exposure.

Comparison to Midwest Bridge Renovation Site

Airborne lead concentrations recorded during this particular bridge renovation were substantially lower than those reported in other geographic regions of the United States for similar repair operations. Lower lead concentrations would be expected due to previous efforts at lead removal; however, even after the supposed deleading of these surfaces, lead exposure greater than the OSHA PEL still occurred. Only during the very thorough renovation undertaken here was the older lead-based paint uncovered. The high variability in exposures measured might be due to differences in environmental conditions as well as variability in individual work practices.

Lead contamination of on-site vehicles followed a pattern similar to that observed by Piacitelli et al. (1995), in that the heavy equipment operator, who wore no protective clothing and had limited airborne lead exposure, had the vehicle with the highest surface lead concentrations. Lead dust at construction sites may infiltrate areas that are thought to be relatively free from contamination, such as heavy equipment and other vehicles not directly involved in high lead-exposure operations.

At this site, hand-washing facilities were provided, although these were infrequently used. No shower facilities were available, and no separate clothes changing facilities provided to minimize the risk of take-home contamination. As stated previously, engineering controls were not effective in reducing the airborne lead exposure to acceptable levels. High variability in airborne lead concentrations may make identification and selection of engineering controls more difficult. Respirator maintenance and cleaning was performed infrequently at best, and when not in use, respirators were often left uncovered, with the possibility for contamination from lead-containing dusts from nearby sources. Changing of clogged or overloaded respirator filters was not observed. The compliance program developed for the contractor seemed to be implemented only partially and therefore had limited effectiveness in reducing worker exposure.

CONCLUSIONS

The primary conclusion that can be drawn from this study is that lead exposure can occur when and where it is least expected. The fact of a structure having been "deleaded" does not necessarily mean that all lead paint has been removed. At this site only the removal of the concrete roadway subsequently revealed the underlying lead-based paint.

There were significant differences in airborne lead concentrations among trade groups. Ironworkers performing metal cutting had the greatest airborne exposure. Painters also had high lead exposure due to the use of powered paint removal equipment in containment. TWAs for ironworkers and painters exceeded the lead PEL on several occasions. Other demolition workers had relatively high exposure to lead-containing dusts, but were more likely not to use respirators or have engineering controls available. Laborers using compressed air for cleaning steel beams had higher levels of dust contamination on clothing than those workers performing metal cutting operations. All contractor vehicles sampled showed some evidence of lead contamination. The heavy equipment operator's personal vehicle was most highly contaminated, possibly due to his being unaware of the presence of lead dust and therefore not taking necessary precautions against contamination.

Even though a lead compliance plan had been developed for this contractor and training had been provided to employees, implementation of environmental controls was poor. Although engineering controls were more likely to be used during tasks associated with highest airborne lead concentrations, their use was inconsistent and generally did not reduce lead exposures to below the action level. Respirator use was more common among those workers exposed to higher airborne lead concentrations, but respirator cleaning and maintenance was substandard. Although some improved lead control technologies are available, these have not been widely accepted by the construction industry. More effective strategies, including development of cost-effective and useable engineering controls, need to be used in reducing lead exposures.

Future research into the problem of lead exposure in construction work should incorporate a sampling strategy that can evaluate the variability of exposures among trades and tasks, and should focus on measuring the effectiveness of engineering controls and personal protective equipment in reducing or eliminating airborne and surface lead.

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