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I. SUMMARY

On November 16, 1992, a request was received from the Brotherhood of Painters and Allied Trades of America, District Council No. 11 for a National Institute of Occupational Safety and Health (NIOSH) Health Hazard Evaluation (HHE) to evaluate occupational health hazards during anticipated renovation of the Goldstar Memorial Bridge in Groton-New London, Connecticut. The request expressed concern regarding the workers' potential to carry home lead-containing dust produced during removal of lead-based paint.

At this work site a crew of typically 5-10 workers performed abrasive blasting and painting inside a total enclosure containment structure designed to reduce fugitive lead emissions to the environment. In addition, abatement-related activities were performed by about 40 workers outside the containment structure. Because the dust generated is concentrated within the structure, the Connecticut Department of Transportation included performance specifications in the Goldstar contract requiring medical monitoring, personal air sampling, personal protective equipment, hygiene facilities, and worker training. The bridge renovation project began in the spring of 1993. The HHE, conducted during September 7-16, 1993, included monitoring of blood lead levels, measurement of personal breathing zone (PBZ) airborne lead exposures, as well as assessment of surface lead levels on skin and clothing and in automobiles.

At the time of the study, employees' blood lead levels (BLLs) ranged from 2.2-16.5 micrograms/deciliter (µg/dL). The mean BLL was 7.2 µg/dL. Thirty-six percent of the workers had BLLs over 10 µg/dL. The 13 employees who worked in or near the containment structure had significantly higher BLLs than the 9 other workers in less exposed jobs (8.9 vs. 4.7 µg/dL, respectively; $p = 0.04$). NIOSH researchers were not able to collect blood from workers in one potentially highly exposed job category, the recycling machine operators.

The arithmetic means of PBZ air lead concentrations for workers in the blaster/painter, apprentice, and recycling equipment operator job categories were higher than the Occupational Safety and Health Administration's (OSHA) 10-hour time-weighted average (TWA) permissible exposure limit (PEL) of 40 micrograms/cubic meter (µg/m^3)(250 µg/m^3 6.25 times PEL; 110 µg/m^3 2.8 times PEL; and 140 µg/m^3 3.5 times PEL, respectively). PBZ exposures for blaster/painters and apprentices were highly variable; for example, among the 24 samples taken from blaster/painters, 16 had air lead concentrations below the PEL, but 3 exceeded 1000 µg/m^3.

Categories of workers having high levels of lead on their hands included the apprentices, blasters, and recycling equipment operators (430, 1000, and 1700 µg/sampling wipe, respectively, at the end-of-shift and before washing). Workers in these same categories had high levels of lead on their clothing (460, 360, and 3100 µg/sampling pad, respectively). Inspectors, security personnel, and industrial hygienists/safety personnel had lower levels of lead on both their hands (64, 10, and 34 µg/wipe, respectively) and their clothing (10, 1.6, and 14 µg/pad, respectively). While skin absorption of lead in paint is not thought to be significant, the presence of lead on skin and clothing may result in accidental ingestion of the lead by the worker and may be an important pathway for carrying the lead dust into the home.

Lead was present in each of the 27 automobiles sampled. The highest lead loadings were found on the driver's floor (geometric mean (GM)=1900 µg/m^2), which suggests that lead is being carried into cars on work shoes. Lead-contaminated skin or clothing is also a source of car contamination, as evidenced by the presence of lead on armrests (GM=1100 µg/m^2) and steering wheels (GM=240 µg/m^2). The mean dust loading on the floor and seat area was highest in cars of the workers in low exposure categories, such as industrial hygiene/safety and security personnel (1000 µg/m^2). Abrasive blasters, who typically had the highest exposures to airborne lead, had the lowest mean dust loading in their cars (370 µg/m^2). These findings may be explained by the observation that blasters regularly changed out of work clothing and showered before entering their cars, whereas other personnel, thought to be only minimally exposed to lead, did not regularly follow these practices.

Data collected at the Goldstar Memorial Bridge renovation site confirmed expectations that blaster/painters and apprentices who entered areas where abrasive blasting occurred were potentially exposed to lead as indicated by high airborne lead levels, as well as skin and clothing contamination. Workers operating recycling equipment also had very high potential exposures, although they did not routinely enter the blasting areas. At this site, workers' blood lead levels were low, below 20 µg/dL, but investigators were not able to obtain blood samples from any of the recycling equipment operators.

Lead may have been carried on workers' skin and clothes into their cars. The degree of lead contamination inside workers' cars was not necessarily associated with those job categories having the highest personal exposures to airborne lead in the work environment. To prevent lead from being carried into cars and homes, personal hygiene practices such as leaving work clothes and shoes at the job site, showering, and changing into clean clothes before leaving the work site are recommended for all personnel involved in or working near lead abatement activities.

Key words: SIC 1622 (bridge, tunnel, and elevated-highway construction); lead; take-home exposures; construction; bridge workers; lead-paint abatement; surface lead contamination

II. INTRODUCTION

On November 16, 1992, the National Institute for Occupational Safety and Health (NIOSH) received a request from the Brotherhood of Painters and Allied Trades of America, District Council No. 11 for a Health Hazard Evaluation (HHE) of occupational hazards during renovation of the Goldstar Memorial Bridge, a two span highway bridge between Groton and New London, Connecticut. Specifically, the requesters asked NIOSH to study the potential for workers to carry lead-containing dust, generated during abrasive blasting, to their homes, thereby posing a risk to their families.

To evaluate this potential, NIOSH investigators visited the bridge site on three occasions:

1. A meeting, organized by the general contractor, was attended on February 9, 1993.
2. A walk-through visit to test the feasibility of the proposed study protocol was made during July 12-16, 1993.
3. The field study September 7-18, 1993.

Work on the bridge had begun four months prior to the September field study and was estimated to be completed in 36 months. The contract to renovate the bridge was awarded to the George Campbell Painting Company of New York. Several subcontractors were also involved in various aspects of the work. A subcontract for industrial hygiene and environmental monitoring services was given to EnviroMed Services, Inc.; the Connecticut Department of Transportation also awarded a contract to KTA Tator Company for paint inspecting services. Some workers operating under these latter two contracts did perform their tasks in the area surrounding the containment structure and were included in the study.

An interim report with preliminary observations was provided to District No. 11 of the Brotherhood of Painters and Allied Trades of America and George Campbell Painting Company on April 15, 1994. Workers have been individually notified by letter of their personal sampling and blood test results.

III. BACKGROUND

A. Lead in construction

Exposure to lead during paint removal from steel structures is recognized as a serious health concern for construction workers. Abrasive blasting, a common paint removal technique, may produce lead dust concentrations which greatly exceed the current Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit of 50 $\mu g/m^3$ (8 hour, time-weighted average).[1] Measures to protect the environment from dust emissions, such as fully-enclosed dust containment structures, may increase worker exposures to lead-based paint (LBP) during abatement activities. Occupational exposures to lead in construction were specifically addressed in the *1993 OSHA Lead in Construction Standard* and the 1992 *NIOSH Alert: Preventing Lead Poisoning in Construction Workers*.[1,2] Both have increased the attention paid to controlling workplace exposures during LBP removal. There is also concern that exposures to lead from bridge painting activities may, in fact, go beyond the workplace.

Para-occupational or "take-home" exposures occur when workers are occupationally exposed to a contaminant and then carry it from the work site, generally on their skin, hair, clothing, or shoes. Previous studies have shown that several workplace contaminants, including lead,[3,4,5,6,7,8,9,10] asbestos,[11] beryllium,[12] and polycyclic compounds[13] have adversely affected the health of workers' families. For example, increased lead absorption has been documented in families of workers at lead smelters,[3,4] battery factories,[5,6,7,8] radiator shops,[9] and electronics plants.[10] In some cases, environmental sampling documented lead contamination (other than from lead paint) in the workers' homes, particularly in areas where dirty work clothes were stored and laundered.[3,4,6,7,8,10] Ingestion of the contaminant through hand-to-mouth activities, especially in young children, is thought to be the primary mechanism of exposure.

Work practices such as using protective clothing and shower facilities are thought to greatly reduce the potential for workers to inadvertently carry contaminants home on their skin or clothing. Such practices may not, however, have been closely followed in the past at construction sites due to the temporary and changing nature of the work environment. For example, access to potable water and/or electricity is often difficult in remote locations.

B. Description of Work Site

The Goldstar bridge consists of two one-mile-length spans, containing approximately 3 million square feet of structural steel coated with LBP; samples of the dried paint contained up to 30% lead by weight. During the study, complete abrasive blast cleaning of the steel was being performed using recycled steel grit. The new coating includes a zinc epoxy primer, an aluminum mastic midcoat, and an aliphatic urethane topcoat.

The area surrounding the bridge site is both residential and business. Included in the residential part is a public housing project with a playground facility. To prevent emissions into this sensitive environment, three fully-enclosed flexible-sided containment enclosures with negative-pressure ventilation were used during abrasive blasting and primary coating of the bridge.

Two containment platforms, located underneath the southbound span, were 2,952 and 2,016 square feet and the northbound span platform was 4,600 square feet. Usually, one enclosure was in use for blasting and primary painting, while the other two were being moved to new locations using rollers attached to the underside of the bridge. During blasting activities, each enclosure held 3-4 blasters working simultaneously, with one apprentice assisting them. Both the lead-based paint particles generated during the blasting and the steel grit used as abrasive were carried in the airstream or settled through the open-grated platform of the containment enclosure into an auger conveyor, which carried the LBP-steel grit mixture to dust collectors/recyclers located on the ground below the containment enclosure.

C. The Work Process

Major jobs at the site included blaster/painters, apprentices, dust recycling equipment operators, paint inspectors, security personnel, and industrial hygiene/safety specialists. Typical job activities for each job are provided in Table 1. To compare lead exposure levels by job title, each job title was assigned *a priori* to a lead exposure category based on the proximity to and length of time spent near lead sources. Although the workers had specific job titles, there was considerable variation in the work performed within a job title. For instance, on any one day only about four "blasters" were actually engaged in abrasive blasting. Others, also in the blaster category, might be painting, moving containment structures, sweeping, rigging lines for fall protection, etc.

A typical workday during the study period included blasting the structure with steel pellets over a period of about four hours, followed by a vacuuming period of one-two hours and a period of painting with a primer coat in the next two hours of the work shift. The primary painting must occur during the same work shift as the blasting to prevent flash rusting, and all work must be performed under strict temperature, humidity and dew point conditions. Both the blasting and the primer painting were performed within the containment structure. The final coatings could be applied at a later time, and full containment was not required.

Two work shifts of construction workers were in operation during the study period. The first shift worked from 7:00 a.m. until 5:00 p.m., the second from 5:00 p.m. until 3:00 a.m. However, irregularities in the shifts were the rule, resulting primarily from equipment failures and inclement weather. During the two weeks of this study, there was an increasing amount of rain and corresponding decrease in blasting later in the study period.

D. Health and Safety Procedures

The Goldstar bridge project benefited from the fact that the Connecticut Department of Transportation incorporated specifications into the contract requiring a health and safety program to cover all workers at the site. Components of this program included employee training, medical surveillance, hazard communication, personal hygiene procedures, protective equipment and clothing, and other procedures deemed appropriate by a certified industrial hygienist hired to write the plan. Medical monitoring was performed by the Connecticut Road Industry Surveillance Project (CRISP), a NIOSH-funded program designed to reduce lead exposure among construction workers. This program resulted in work practices which may not be typical for all bridge sites.

Before the start of their shift, workers were expected to arrive at a staging area (located about 700 feet from the work site), change into work clothing, receive individual work assignments from the site supervisor, and obtain suitable respiratory protection. Type CE blasting helmets were used by the blasters, and frequently these were supplemented by quarter-face, high efficiency, particulate air (HEPA) filtered respirators worn underneath. A bus carried most of the workers from the staging area to the work area. At the end of shift, any highly contaminated workers, especially those who had been inside the containment structure, were bused to the staging area, although this practice was not consistently followed and, at times, the workers walked.

Workers at the site were provided work clothing if they performed tasks judged to be dusty, or upon request. Separate men's and women's decontamination trailers, with rooms for changing clothes, showering, and clothes storage, were available in the staging area. Another trailer was used for respirator training, cleaning, and storage. Portable hand-wash stations with running water were located near areas where employees took rest and meal breaks. These stations were powered by gasoline generators and provided storage for the lead-contaminated wastewater, but they were not always operable.

Workers performing environmental, industrial hygiene, paint inspection, and safety services usually provided their own work clothing and did not routinely take showers prior to leaving the site. In some cases, their work shifts were modified to the needs of the operation (e.g., the respirator cleaners began their workday in the afternoon, close to the end of the first shift).

IV. MATERIALS AND METHODS

A. Study Population

Workers were considered eligible for participation in the study if their primary work location was near the blasting areas. Each worker agreed to participate for a three-day period. Day shift workers were sampled on September 9, 11, 12, 13, 14, and 15; evening shift workers were sampled on September 15 and 16. Of 50 workers eligible, 33 signed consent forms agreeing to participate (66% participant rate). Eight of the study participants dropped out of the study, because they terminated employment prior to the study (2 persons), became ill (2 persons), or were unable to tolerate wearing the sampling pumps beyond a few hours (4 persons), leaving 25 workers who participated in the study. Non-participant questionnaires were obtained from 14 (82%) of the non-participants. Nine of the 14 indicated that their primary reason for not participating was that they believed wearing industrial hygiene sampling pumps would present a problem in performing their job tasks (which frequently involved climbing or working around machinery).

B. Medical Evaluation

A blood sample for measurement of lead and zinc protoporphyrin (ZPP) was obtained from 22 of the 25 workers at the end of the three days of industrial hygiene sampling. A duplicate blood sample for each worker was sent to the laboratory as a blind check of laboratory quality control. The blood specimens were analyzed by the CRISP contract laboratory, which is approved by OSHA for occupational blood lead testing. Blood lead levels were determined by graphite furnace atomic absorption spectrophotometry, and ZPPs were determined by hemoflurometric techniques.

C. Environmental Evaluation

1. Personal Breathing Zone Air Samples

To estimate exposures to airborne lead, all participating workers had full-shift personal breathing zone air samples collected outside any personal protective equipment and generally on the shirt lapel for three consecutive days. If the worker wore a blasting helmet, a sample was also collected inside it. Ten-hour, time-weighted average (TWA) exposures for each worker were determined.

Air samples were collected following NIOSH Sampling and Analytical Method 7082[14] on 37 millimeter (mm) diameter, 0.8 micrometer (µm) pore size, polyvinyl chloride in closed-face cassettes. Personal air sampling pumps were calibrated at 1.0 liter per minute for samples collected outside blasting helmets and were calibrated at 2.0 liters per minute for samples collected inside blasting helmets. The different flow rates were used to minimize particulate loading on the filter and, therefore, the frequency of filter changes.

Samples were weighed for total mass and analyzed for inorganic lead at a NIOSH contract laboratory using flame atomic absorption spectroscopy following NIOSH Method 7082[14]. Samples below the limit of quantification were reanalyzed using a graphite furnace atomic absorption spectroscopy following Method 7105[15] which is a more sensitive method. All field samples were blank-corrected.

2. Skin Wipe Samples

a. Handwipes

Workers' hands were sampled for lead using commercial wet-wipes (Wash 'n Dri ™ Moist Towelettes). Each worker was instructed to remove a wet wipe from its container and wipe for 15 seconds over both hands up to the wrist, including between fingers, under fingernails, and over the front and back surfaces. Hand sampling sessions were: at the morning break, before lunch, at the afternoon break, before washing at the end-of-shift, and after washing at the end-of-shift. The timing of these sessions proved to be highly variable due to individual irregularities in daily work patterns.

The before and after end-of-shift washing was specifically targeted to evaluate the effectiveness of the workers' washing procedures before leaving the work site. For most workers, the washing procedure included showering. In addition to end-of-shift washing, handwashing occurred periodically throughout the day. For this reason, the worker was asked whether or not s/he had washed in the preceding hour every time skin sampling occurred.

b. Facewipes

Lead dust on workers' faces was sampled using techniques similar to those of the handwipes: samples were timed for 15 seconds per wet wipe. However, workers were asked to wipe their faces only once, before showering at the end of the work shift. As with the hand wipe sampling, the workers' responses to a question regarding face washing activity in the hour prior to our sampling were recorded.

Both handwipe and facewipe samples were digested according to NIOSH Method 9100[14] modified for matrix, and analyzed for inorganic lead using atomic absorption spectroscopy (Method 7082[14]).

3. Clothing Patch Samples

Lead on clothing was estimated from dry cotton gauze pads attached to the workers' clothing in a modification of a technique suggested by Durhan and Wolfe [1962] [as reported by the USEPA 1986[16]]. Individually wrapped, 2 inch x 2 inch pads (Johnson & Johnson™) were attached by safety pins to workers' clothing at four locations: right and left lateral forearms, and right and left anterior thighs. The pads were attached at the beginning of the shift and were left in place throughout the work day. Worker's clothing was sampled during each of the days that air monitoring and skin wipe sampling were performed.

Gauze pads were digested according to NIOSH Method 9100[14] modified for matrix, analyzed for lead according to NIOSH Method 7082[14], and were blank corrected.

4. Car Samples

Two types of dust collection methods were used to collect dust samples from inside each car, depending on the surface sampled. Wipe sampling was performed on hard, smooth surfaces (including vinyl floormats, seats, and armrests; dashboard; and steering wheel) using commercial wet-wipes (Wash'n Dri™ Moist Towelettes) by NIOSH Method 9100[14]. On fabric surfaces, a vacuum sampling method, originally developed by Que Hee *et al.*, was used to collect dust samples.[17] In order to ensure that there was a detectable amount of particulate in each vacuum sample, a single composite sample from both the driver's floor and seat areas was collected. The vacuum sampler consisted of a collection nozzle connected by Tygon® tubing to a closed-face cassette containing a polyvinyl chloride filter (37 mm diameter, 5.0 µm pore size), and a personal air monitoring pump operated at 2.0 liters per minute. The collection nozzle was a short [about 5 centimeter (cm) long] piece of stainless steel tubing (6 mm i.d.) with the sampling end crimped to form an opening of approximately 10 mm by 4 mm. Dust from the same surfaces were not always collected for each car, if not feasible (e.g., a wipe was not taken on the floor if no vinyl mat was present).

Prior to collecting either type of sample, the surface was delineated using a disposable plastic template with interior dimensions of 18 cm by 18 cm, if the size of the surface was large enough. Otherwise, the sample area was measured using a ruler. Depending on the location, either a clean collection nozzle or a fresh wet-wipe was then drawn across the sample surface using a series of horizontal strokes, followed by a series of vertical strokes, and then by another series of horizontal strokes, for a total of three passes over the same surface.[17] The same cassette was used to sample both the floor and seat areas in each car whereas a new wipe was used for each surface sampled.

For comparison, separate wipe samples and a composite vacuum sample were collected on the driver's floor and the seat in some cars. The vacuum and wipe samples were taken adjacent to each other so that the same surface was not sampled twice.

Samples were analyzed for lead using atomic absorption spectrophotometry following NIOSH Method 7082[14].

D. Statistical Analyses

Data were analyzed using the Statistical Analysis System (SAS).[18] In many cases, analysis of the sampling data by the Shapiro-Wilk test indicated that transformation of the data was needed. Because the data appeared to be distributed lognormally, geometric means (GM) and geometric standard deviations (GSD) were calculated. For statistical calculations, lead levels below the laboratory's limit of detection (LOD) were assigned a value equal to the LOD divided by square root of two, as suggested by Hornung *et al*.[19]

Most personal samples were repeated on three consecutive days for the same worker. For some workers, missing values occurred because of irregular work patterns. Typically, repeated measurements with missing values require a statistical analysis such as generalized estimating equations (GEE)[20] to take into account the lack of independence among observations. Unfortunately, GEE could not be used with six job categories because of the relatively small number of workers available and consequent insufficient degrees of freedom. The investigators decided that, for purposes of description, it would be more informative in this report to keep the job categories and treat the samples as if they were independent observations.

For some analyses, repeated measures on an individual were averaged. When averages were calculated, Tukey's Studentized range test or paired t-tests permitted between group comparisons. Differences were considered significant if the probability was less than 0.05 ($p<0.05$). Correlations were estimated by

Pearson or Spearman tests and considered to be statistically significant if the p was less than 0.05.

Box plots presented in this report allow visual comparisons of the overall data for each day of sampling. The box represents the middle 50% of the data values (between the 25th and 75th quartiles, called the interquartile range). The vertical lines or whiskers extend out from each box to a maximum distance of 1.5 interquartile ranges and include about 99% of the normally distributed data. Data outside this range are indicated by circles. The lines connecting the box plots show the positions of the means of the data and are useful for visualizing trends occurring with time.

V. EVALUATION CRITERIA

A. General guidelines

To assess the hazards posed by workplace exposures, NIOSH investigators use a variety of environmental evaluation criteria. These criteria suggest exposure levels to which most workers may be exposed for a working lifetime without experiencing adverse health effects. However, because of wide variation in individual susceptibility, some workers may experience occupational illness even if exposures are maintained below these limits. The evaluation criteria do not take into account individual hypersensitivity, pre-existing medical conditions, possible interactions with other workplace agents, medications being taken by the worker, or environmental conditions.

Evaluation criteria for chemical substances are usually based on the average personal breathing zone exposure to the airborne substance over an entire 8- to 10-hour workday, expressed as a TWA. Personal exposures are usually expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). To supplement the 8-hr TWA where there are recognized adverse effects from short-term exposures, some substances have a short-term exposure limit (STEL) for 15-minute peak periods; or a ceiling limit, which is not to be exceeded at any time. Additionally, some chemicals have a "skin" notation to indicate that the substance may be absorbed through direct contact of the material with the skin and mucous membranes.

The primary sources of evaluation criteria for the workplace are: NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[21] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[22] and the OSHA PELs.[23] These criteria typically change over time as new information on the toxic effects of an agent become available.

The OSHA PELs reflect the economic feasibility of controlling exposures in various industries, public notice and comment, and judicial review; whereas the NIOSH RELs are based primarily on concerns related to the prevention of occupational disease. An additional complication is due to the fact that a Court of Appeals decision vacated the OSHA 1989 Air Contaminants Standard in *AFL-CIO v OSHA*, 965F.2d 962 (11th cir., 1992); OSHA is now enforcing the previous 1971 standards (29 CFR 1910.1000, Table Z-1-A).[24] However, some states which have OSHA-approved State Plans will continue to enforce the more protective 1989 limits. NIOSH encourages employers to use either the 1989 limits or the RELs, whichever are lower.

B. Lead - Adult Exposures

Lead is ubiquitous in U.S. urban environments due to the widespread use of lead compounds in industry, gasoline, and paints during the past century. Exposure to lead occurs via inhalation of dust and fume, and ingestion through contact with lead-contaminated hands, food, cigarettes, and clothing. Absorbed lead accumulates in the body in the soft tissues and bones. Lead is stored in bones for decades, and may cause health effects long after exposure as it is slowly released in the body.

Symptoms of lead exposure include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort (colic), fine tremors, and "wrist drop."[25,26,27] Overexposure to lead may also result in damage to the kidneys, anemia, high blood pressure, infertility and reduced sex drive in both sexes, and impotence. An individual's blood lead level (BLL) is a good indication of recent exposure to, and current absorption of lead.[28] The frequency and severity of symptoms associated with lead exposure generally increase with the BLL.

The overall geometric mean BLL for the U.S. adult population (ages 20-74 yrs) declined significantly between 1976 and 1991, from 13.1 to 3.0 micrograms per deciliter of blood (µg/dL)--this decline is most likely due primarily to the reduction of lead in gasoline. More than 90% of adults now have a BLL of <10 µg/dL, and more than 98% have a BLL <15 µg/dL.[29]

Zinc protoporphyrin (ZPP) levels in the blood tend to elevate with prolonged lead exposure. Such elevation is considered to be more of an indicator of past chronic exposure than is the blood lead level. ZPP concentrations of humans not known to be occupationally exposed to lead are in the range of 16-23 µg/dl of blood with an upper limit of approximately 35 µg/dl.[30]

Under the OSHA general industry lead standard (29 CFR 1910.1025), the PEL for airborne exposure to lead is 50 µg/m^3 (8-hour TWA).[31] The standard requires proportionally lowering the PEL to compensate for shifts exceeding

8 hours (e.g., the PEL for a 10-hour shift is 40 µg/m^3), medical monitoring for employees exposed to airborne lead at or above the action level of 30 µg/m^3 (8-hour TWA), medical removal of employees whose average BLL is 50 µg/dL or greater, and economic protection for medically removed workers. Medically removed workers cannot return to jobs involving lead exposure until their BLL is below 40 µg/dL. The OSHA interim final rule for lead in the construction industry (29 CFR 1926.62) provides an equivalent level of protection to construction workers. ACGIH has proposed a TLV for lead of 50 µg/m^3 (8-hour TWA), with worker BLLs to be controlled to at or below 20 µg/dL, and designation of lead as an animal carcinogen.[32] The U.S. Public Health Service has established a goal, by the year 2000, to eliminate all occupational exposures that result in BLLs greater than 25 µg/dL.[33]

The occupational exposure criteria described above are not protective for all the known health effects of lead. For example, studies have found neurological symptoms in workers with BLLs of 40 to 60 µg/dL, and decreased fertility in men at BLLs as low as 40 µg/dL. BLLs are associated with increases in blood pressure, with no apparent threshold through less than 10 µg/dL. Fetal exposure to lead is associated with reduced gestational age, birthweight, and early mental development with maternal BLLs as low as 10 to 15 µg/dL.[34] Men and women who are planning to have children should limit their exposure to lead.

In homes with a family member occupationally exposed to lead, care must be taken to prevent "take home" of lead, that is, lead carried into the 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.[35] Particular effort should be made to ensure that children of persons who work in areas of high lead exposure receive a blood lead test.

C. Lead - Childhood Exposures

The adverse effects of lead on children and fetuses include decreases in intelligence and brain development, developmental delays, behavioral disturbances, decreased stature, anemia, 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.[34]

No threshold has been identified for the harmful effects of lead in children; the Centers for Disease Control and Prevention (CDC) currently recommends a multitier approach to defining and preventing childhood lead poisoning, based on BLL screening.[36] 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; ≥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.

Although U.S. population blood lead levels have declined since 1976, recent national estimates indicate that 8.9%, or about 1.7 million children under 6 years have elevated BLLs (≥ 10 µg/dL).[37]

D. Lead in Surface Dust

There are currently 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, cigarettes, or food contaminated by lead dust. Previous studies have found a significant correlation between resident children's BLLs and house dust lead levels.[38] 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: floors, 200 micrograms per square foot (µg/ft^2); window sills, 500 µg/ft^2, and window wells, 800 µg/ft^2. HUD also recommends the standard for floors be applied to exterior porches.[39] These criteria were established as feasible limits for clearance following final cleaning during residential lead-based paint abatement.

VI. RESULTS AND DISCUSSION

A. MEDICAL

For statistical analyses, the values for BLL and ZPP in the duplicate blood samples taken from each worker were averaged. No employee had a BLL in excess of current occupational exposure criteria, and none had an elevated ZPP. The mean BLL in the 22 workers was 7.2 µg/dL (range 2.2 - 16.5), and the mean ZPP was 17.2 µg/dL (range 9.5 - 23.5). Thirty-six percent of the workers had BLLs over 10 µg/dL. The 13 employees who worked in or near containment had significantly higher BLLs than the 9 workers in less exposed jobs (8.9 vs. 4.7 µg/dL, respectively; $p = 0.04$).

The blind duplicate samples submitted for analysis allowed an evaluation of laboratory quality control. For 7 of the 22 workers (32%), the coefficient of variation (CV) between the two samples was greater than the generally acceptable limit of 15%. For ZPP, 1 of the 22 pairs (4.5%) had a CV greater than 15%. This indicates some variation in the blood lead results from this laboratory and suggests that small changes in BLLs in these workers over time should be interpreted cautiously.

It appears that at the time of our study the workers were not excessively exposed to lead as reflected by the low BLLs. However, blood samples were not obtained from any recycling equipment operators, a group with potential for high lead exposure. It should also be noted that, because of equipment failures and inclement weather, full-time blasting work at this site had only just begun prior to our study. Since BLLs may reflect lead exposure over a longer period of time, our results may be more indicative of the low exposure environment prior to the study.

B. ENVIRONMENTAL

1. Personal Breathing Zone Air Samples

In general, the personal breathing zone (PBZ) data reflect the work processes which were noted during the study. Figure 1 shows a reduction in PBZ lead exposure which coincides with a reduced amount of blasting time due to adverse weather conditions which developed during the second week of the study.

Table 2 gives the summary statistics of the PBZ samples for the different job categories. The arithmetic means for the apprentices, blasters, and recycling equipment operators were much higher than the other categories of workers and were much higher than the 10 hour TWA PEL of 40 microgram/cubic meter. The mean for the apprentices of 110 $\mu g/m^3$ was 2.8 times the PEL, the mean for the recycling equipment operators of 140 $\mu g/m^3$ was 3.5 times the PEL, and the mean for the blasters of 250 $\mu g/m^3$ was 6.25 times the PEL. Also of note, is the very high standard deviations of the apprentices and blasters. Such variation suggests that individual blasters and apprentices received much higher exposures than others in the same job categories. This is to be expected because only a few workers actually performed blasting on any one day, and those engaged in this activity would have received the highest exposures.

Despite the apparent validity of the PBZ data, limitations due to the environmental conditions at this construction site cannot be ignored. Work was frequently performed many feet above the ground. Under these circumstances a sampling pump, tubing, and cassette could become entangled with safety lines or hamper movement in tight spaces. During abrasive blasting within a containment structure, conditions were cramped, visibility was restricted due to dust and blasting helmets, and hearing was limited due to noise. Additional persons in the area increased the chance of accidents so industrial hygienists were frequently not able to observe the performance of the sampling apparatus or to change cassettes. The helmets also interfered with the positioning of the cassettes within the breathing zone because there was no ideal place for attachment. The cassette's position was adjusted to be on the anterior surface of the body but somewhat lower than the standard breathing zone position on the lapel.

Cassettes of the workers within the containment structure during abrasive blasting quickly became overloaded with particulates even though the flow rate on the pump was set for the minimum of one liter per minute. If the NIOSH recommended loading limit of 2 milligrams of dust per cassette were observed, the cassettes on the blasters should have been changed about every 15 minutes a rate which, under the conditions, was impossible.[14] In fact, a change rate of once every 4 hours was more typical. Overloaded cassettes were not removed from the data set unless the pumps had faulted. Nevertheless, exposures of the blasters and apprentices may be underestimated due to the possibility of reduced flow through the filters.

An attempt was made to sample inside the blasting helmets in addition to the more standard position outside the helmet. However, a NIOSH industrial hygienist within the containment structure observed that, after completing blasting, workers rested for about 15 minutes while dust settled, then removed the blasting helmets. Of course, when the blasting hoods were removed, inside samples were exposed. Because of uncertainties with the interpretation of samples collected within blasting helmets, these data are not presented in this report.

2. Skin Wipe Samples

Figures 2, 3, and 4 show box plots of the lognormally transformed skin wipe data. Figure 2 shows the handwipe boxplots for workers reporting no hand washing in the previous hour, Figure 3 shows the boxplots for workers reporting hand washing, and Figure 4 shows the boxplots of the facewipes. Workers report washing in the previous hour for only four of the facewipe samples (not included in the figures). As with the PBZ samples, there is a general downward trend over the study period, reflecting decreased blasting activity. There was no significant correlation between the time of day the sample was taken and the lead recovered on the wipe for either handwipes or facewipes (Spearman, α= 0.05). Consequently, these data were not corrected for time of day.

Table 3 presents the summary statistics for lead levels on workers' skin. For workers not washing in the hour prior to sampling, significantly less lead was found on workers' faces than their hands (52 vs. 141 µg/wipe, respectively, t-test, p=0.0004). Workers reporting washing activity had significantly less lead on their hands than if they reported no washing (141 vs. 58 µg/wipe, respectively, t-test, p=0.0001).

Handwipes collected at the end of the shift may provide relevant data about lead carried home on skin. These data are presented by job category in Table 4. Before washing, the samples fell into two distinct groups. The group having higher levels of lead on their hands includes the apprentices, blasters, and recycling equipment operators (430, 1000, and 1700 µg/wipe, respectively). Lower levels of lead were found in the inspectors, security personnel, and industrial hygienist/safety personnel (64, 10, and 34 µg/wipe, respectively). This grouping is not unexpected, with the exception of the single sample from a recycling machine operator. A high level of skin contamination on the operator might not be anticipated because s/he does not regularly enter the containment structure. However, it is reasonable that this worker may be subject to high lead levels while maintaining and cleaning grit recycling equipment. More samples would be required to confirm that hand contamination of recycling equipment operators is consistently high.

Lead from paint is thought not to be absorbed into the body through the skin but lead on the skin, particularly on the face and hands, could be accidentally eaten or be carried into a vehicle or the home. For this reason, it is advisable to achieve the lowest possible amount of lead on the hands. The data (Table 4) confirm that the differences between lead on the hands before and after the washing procedure for the apprentices blasters and recycling equipment operators is quite high (360, 950, 1600 µg/wipe, respectively), indicating that the washing is quite effective at removing lead in the high exposure groups of workers. For the lower exposed categories of workers, the lead recovered from the hands was consistently lower after washing than before suggesting that washing was effective, although this difference is not statistically significant (inspectors and industrial hygienists/safety personnel, differences of 58 and 27 µg/wipe, respectively). The lead levels on the hands of the highly exposed group *after* washing (apprentice, blaster, and operator arithmetic means = 65, 84, and 64 µg/wipe, respectively) were similar to the levels on the hands of the lower exposed groups *before* washing (inspector, security, and IH/safety personnel arithmetic means of 64, 10, and 34 µg/wipe, respectively). It is possible that either additional washing or more care in preventing recontamination of the higher exposed groups after end-of-shift washing procedures could result in even lower lead levels on their hands.

3. Clothing Samples

Although the gauze pads remained on the worker's clothing throughout the normal work shift, these shifts were irregular. It was found that the longer the shift (lapsed time), the greater the amount of lead found on the gauze (lead loading). This significant correlation between lapsed time and lead loading (Spearman, p=0.0001) provides verification that the gauze pad sampling reflects clothing contamination occurring over the total work day.

To allow comparisons among the different sampling days, the data were adjusted by dividing the individual lead loadings by their lapsed time. Figure 5 shows the box plots of the adjusted lead loading of the gauze patches on each day of the study. As with other sample types, gauze pad contamination shows a general decline corresponding to the reduction in the amount of abrasive blasting. Table 5 gives the summary statistics of the lead levels on the workers' clothing. The workers' arms (means = right arm and left arm, 170, 260 µg/pad, respectively) were significantly less contaminated than their thighs (means = right thigh and left thigh, 490, 340 µg/pad, respectively) (paired t-test, p=0.008).

An arithmetic average of the four patches for each worker on each day of sampling was calculated; this average value is referred to as the representative lead loading. Summary statistics for these representative loadings by job categories are given in Table 6. With one exception, workers in those categories that involve working in the containment structure (apprentices and blasters, 460 and 360 µg/pad) are higher than those in categories that do not (inspectors, security, industrial hygiene/safety personnel, 10, 1.6, and 14 µg/pad, respectively). One unexpected result is that of the recycling machine operator job category whose representative lead loading mean was 3100 µg/pad. Although there are a limited number of samples (n=2) for this category, the very high loading suggests that workers who maintain recycling equipment may be exposed to a high degree of clothing contamination.

4. Car Samples

The workers who permitted their cars to be sampled do not exactly correspond to those who agreed to participate in the personal sampling. Twenty-seven of the 50 workers (54%) at the site agreed to have their personal vehicles sampled for lead. The median length of time spent in the construction industry by study participants was 16 years (range: 3-28 years); all respondents had previously worked at other construction sites. Almost half (48%) of the participants reported that young children (less than 6 years old) regularly ride in their car (i.e., at least once a week). All participants (100%) reported that eating, drinking, or smoking sometimes occurred in their cars. About one-half of the all cars sampled (38, 71, and 57% in the high, medium, and low exposure groups described in Table 1, respectively) had been vacuumed within the last month.

While the high and low *a priori* exposure categories were confirmed by the PBZ, skin wipe, or clothing pad data which were collected at the work site, the medium category is problematic. As was pointed out in preceding sections, recycling equipment operators in particular, may have high lead exposures, especially with regard to skin and clothing contamination. Unfortunately, there was insufficient data to be able to characterize how often these workers are exposed to high lead levels. Consequently, it was decided to retain the *a priori* exposure categories determined on the basis of professional judgement.

Lead loadings on interior surfaces of cars which were measured by the wipe method are presented in Figure 6. The highest loadings were found on the driver's floor and the driver's armrest (GM=1900 and 1100 $\mu g/m^2$, respectively). The GM for any of the other surfaces was below 500 $\mu g/m^2$. Only the difference between mean values for the driver's floor (1900 $\mu g/m^2$) and steering wheel (240 $\mu g/m^2$) were statistically significant ($p<.05$). The variance in lead loading from similar locations was fairly stable between cars (GSDs from 2.3 to 2.9).

Lead loadings on the driver's floor and seat as determined by the vacuum method are shown for each job category in Table 7. The highest GM was for the industrial hygiene/safety specialists (2000 $\mu g/m^2$). The blaster/painters had the lowest GM (340 $\mu g/m^2$); sampling results between blaster/painter cars were highly variable (GSD=9.4) compared to results for other categories. None of the differences between categories were statistically significant at $p=0.05$.

The vacuum sample results are presented by exposure category in Figure 7. The highest lead loadings were found in cars of workers in the "low" exposure group although none of the groups were significantly different from the others. Similar to results for individual jobs, vacuum sampling results were highly variable within exposure groups.

The vacuum and wipe results are not highly correlated in those 21 cars in which both a floor wipe and a composite vacuum sample were taken ($r=0.30$; $p=0.18$) (results not shown). The correlation between vacuum results and seat wipe results was also low ($r=.40$; $p=.42$); however, seat wipes were taken in only six cars. The mean of all vacuum composite samples was 630 $\mu g/m^2$ which is much lower than the sum of the individual means for the floor (1900 $\mu g/m^2$) and seat (380 $\mu g/m^2$) wipe sample results.

Detailed questionnaire data (including work histories, protective clothing usage, and personal hygiene practices) were obtained for 20 of the 27 participants (74%) and are presented by exposure category in Figure 8. Twenty-five percent of the workers in the "low" exposure category reported that they wore company-supplied work clothes, change from work clothes, or shower before going home; 50% took work shoes home. Most workers in the "high" exposure group wore company work clothes (100%), change from work clothes before going home (100%), and shower (90%); none took their work shoes home. More workers in the "low" exposure group (75%) than in the other two groups (high = 40%; medium = 50%) thought that they usually carried lead home.

Questionnaire responses and observations during the survey indicated that most of the workers in the "high" and "medium" exposure groups regularly wore company-supplied work clothes and then changed from their work clothes/shoes and showered before entering their cars. However, workers in the "low" exposure jobs did not wear company work clothes but rather wore their street clothes into work areas and then into their cars, frequently without washing their hands and faces. In fact, many workers in the "low" exposure group were observed to drive their personal cars into the work areas when performing job duties, such as checking sampling equipment, monitoring workers, or maintaining hygiene facilities.

These findings were surprising considering that most workers in the "low" exposure group were industrial hygienists--the same people who had received extensive training in preventing lead exposures and who are professionally responsible for ensuring that other workers are protected from lead hazards. It is possible that the industrial hygienists at this site had underestimated the potential for contaminating their own skin and clothing, perhaps due to their minimal time spent in any areas with high airborne lead concentrations. While their activities in the work areas may be brief and not result in significant inhalation exposures, often they involve contact with lead-contaminated surfaces. Work clothing and hygiene facilities were made available to **all** workers at this construction site but their usage was emphasized only for those workers in highly exposed jobs, those above the airborne lead PEL of 50 $\mu g/m^3$--as minimally required by the OSHA interim final rule for lead in the construction industry (29 CFR 1926.62).

Differential use of shower and changing facilities by high, medium, and low exposure groups is a logical explanation for the observed differences in lead contamination inside cars only if the measured contamination reflects primarily recent deposition. Construction work at the current bridge site had started only two months prior to this survey and most participants had spent over 16 years in the construction industry. While work clothing and hygiene facilities were made available to all workers at this particular survey site, such measures were generally not provided at most construction sites prior to the enactment of the OSHA Lead Standard in May 1993.[2]

Based on this information, we assume that prior to the work on this bridge in the fall of 1993, even highly exposed workers would generally not have had access to shower and changing facilities. Although there is no way to directly determine when the lead was deposited inside automobiles, there is some reason to believe that the contamination levels measured in this study reflect primarily exposures at the current bridge site. First, lead particulate is most likely being constantly removed from, as well as deposited onto, smooth surfaces which are frequently touched such as armrests, the steering wheel, and vinyl seats. Second, lead dust deposited onto rough surfaces such as cloth seats and carpeted floors likely gets "ground-in" and bound within the fabric fibers over time.

Both the wipe and vacuum sampling methods used in this study are fairly non-aggressive (i.e., they tend to collect only loosely-bound particulate from the top of most surfaces). In fact, the vacuum method was specifically designed not to collect total lead on a surface but rather only the loose dust that would most likely stick to a person's hands.[15] Since it is unlikely that lead which may have been deposited several months earlier was still present and loose inside automobiles, we believe that the lead collected in this study was primarily a result of recent contamination and essentially reflects current workplace conditions and hygiene practices.

VII. CONCLUSIONS

Those workers who entered the containment structures during abrasive blasting of the Goldstar Memorial Bridge, the blasters/painters, apprentices, and recycling equipment operators were exposed to high levels of lead outside of the blasting helmets or respirators. These same groups of workers also had high levels of lead on the skin and clothing. The one group of workers who did not routinely enter containment, but whose sampling results indicated high lead exposures, were the recycling equipment operators. This specialized task engaged only a few workers, so only a small number of samples were available. Further sampling is needed to confirm the possible high lead exposures of workers in this job category.

Despite the high potential exposures to lead dust, the relatively low worker blood lead levels suggest that the contract specifications and resulting health and safety programs at the Goldstar Bridge construction site protected the workers. However, the overall effectiveness of the health and safety programs can only be considered tentative for two reasons. First, because there is a question of whether blasting was full-time for a sufficient period prior to the NIOSH study to produce lead exposures comparable to those seen at other bridge construction sites[2] and, second, because one group of potentially highly exposed workers, the recycling equipment operators, did not participate in the blood sampling.

The data presented here strongly suggest that lead may have been carried from the construction site into workers' cars, especially for those workers who were thought to be in a low exposure category and were not required to follow end-of-shift personal hygiene procedures. Clothes and shoes worn in work areas may have resulted in lead dust contamination of cars. Many provisions of the OSHA Lead Standard, which are intended to prevent lead-contaminated skin and clothing from leaving the workplace, are limited in coverage. All construction workers exposed to lead, regardless of airborne exposure level, should follow steps to keep lead from being carried on clothing and skin into their cars and homes.

VIII. RECOMMENDATIONS

The following recommendations are made with respect to abrasive blasting of LBP during bridge maintenance, or other similar construction activities.

1. Ensure that workers use respiratory protection at all times when they are within containment structures. Workers should not assume that clearance of visible dust after a period of abrasive blasting indicates that it is safe to remove respirators.

2. Educate workers so that they understand that all tasks at a construction site may result in high lead exposures, even though the exposures may not be obvious. For instance, there are indications that those workers who maintain the recycling

equipment are exposed to very high air lead concentrations, and to hand and clothing contamination, although they work primarily outside of the containment structure. Such understanding should be backed by a commitment by the general contractor to provide easy access to handwashing facilities and clean personal protective equipment for all workers, as well as requirements that they be used appropriately before eating, drinking, or smoking.

3. The most direct way to prevent ingestion which may result from "take-home" exposures is to ensure that lead dust from contaminated skin and clothing never gets into the workers' cars and homes. Control the amount of lead leaving the construction site by requiring all workers exposed to lead, regardless of level, to change out of work clothing and shoes and wash skin and hair, preferable by showering, before leaving the work site. Keep street clothes away from dirty work clothes. Clean items such as tools and lunch boxes before putting them in personal vehicles. Do not carry lead-contaminated equipment (e.g., helmets, work clothing, work shoes) in personal vehicles. Regularly clean the inside of any car driven to the work site using the methods described in recommendation #4.

4. Never drive personal cars into work areas, and park them away from the work site. Any vehicles which are used when performing job-related duties should be properly cleaned to remove lead contamination before the vehicle is driven from the work site. The interior of vehicles should be vacuumed using a high-efficiency particulate (HEPA) vacuum cleaner. HEPA vacuum cleaners are specially designed to prevent the release of collected dust back into the air. Employers should provide a HEPA vacuum cleaner at the work site for employees to use for cleaning their vehicles. Some surfaces of the interior may be washed using a detergent containing tri-sodium phosphate (TSP), which can be found in most hardware or paint stores. Rinse wash rags and change the rinse water often to prevent spreading lead to clean areas.

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