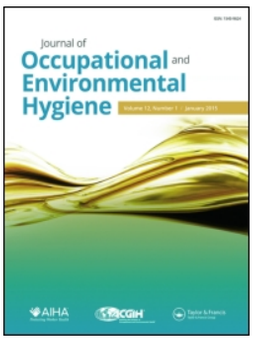

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Skin and Surface Lead Contamination, Hygiene Programs, and Work Practices of Bridge Surface Preparation and Painting Contractors

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A 2005 regulatory review of the lead in construction standard by the Occupational Safety and Health Administration (OSHA) noted that alternative pathways of exposure can be as significant as inhalation exposure and that noncompliance with the standard pertaining to hygiene facilities and practices was the second most commonly violated section of the standard. Noncompliance with provisions of the standard and unhealthy work and hygiene practices likely increase the likelihood of take-home lead via contaminated clothing, automobiles, and skin, thus contributing to elevated blood lead levels (BLL) among construction workers and their family members. We performed a cross-sectional study of bridge painters working for small contractors in Massachusetts to investigate causes of persistent elevated BLLs and to assess lead exposures. Thirteen work sites were evaluated for a 2-week period during which surface and skin wipe samples were collected and qualitative information was obtained on personal hygiene practices, decontamination and hand wash facilities, and respiratory protection programs. Results showed lead contamination on workers' skin, respirators, personal automobiles, and the decontamination unit, indicating a significant potential for take-home lead exposure. Overall, the geometric mean (GM) skin lead levels ranged from 373 μg on workers' faces at end of shift to 814 μg on hands at break time. The overall GM lead level inside respirators was 143 μg before work and 286 μg after work. Lead contamination was also present inside workers' personal vehicles as well as on surfaces inside the clean side of the decontamination unit. Review of the respiratory protection programs, work site decontamination and hand wash facilities, and personal hygiene practices indicated that these factors had significant impact on skin and surface contamination levels and identified significant opportunities for improving work site facilities and personal practices. Elevated lead exposure and BLL can be minimized by strict adherence to the OSHA provisions for functioning decontamination and hygiene facilities and healthy personal hygiene practices.

Keywords bridge painting, construction industry, lead exposure assessment, personal hygiene, skin exposures, surface contamination, work practices

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INTRODUCTION

Lead poisoning of construction workers engaged in the maintenance, repainting, or demolition of steel structures has previously been reported in the literature.[1–7] In 1993, the Occupational Safety and Health Administration's (OSHA) lead in construction standard (29 CFR 1926.62) came into effect. The standard contained several mandates to ensure worker protection from health hazards of lead including: a lowered permissible exposure limit (PEL) of 50 μg/m^3, provisions for respiratory protection, protective clothing, decontamination facilities, healthy work practices, medical surveillance, medical removal protection, training, and air monitoring methods among others.[8]

Since the implementation of this standard, a number of studies have reported significant declines in blood lead levels (BLL) for some construction trades;[9,10] however, elevated BLLs (defined as BLL >25 μg/dL) continue to occur among workers in the construction industry, particularly among laborers, painters, and deleaders who frequently report BLLs >40 μg/dL.[4,5,10,11] Consistent with the nationwide trend, the Massachusetts Occupational Lead Registry reported a 48% decline in cases of BLL >40 μg/dL from the period 1996 to 2001, yet in 2001, construction painters and deleaders constituted 77% of the workers with BLL >40 μg/dL.[10] In 2005, OSHA conducted a regulatory review of the lead in construction standard and concluded that retention of the standard was necessary for continued worker protection, especially for

bridge painters and deleaders who can experience high lead exposures and blood lead levels.[11]

The 1993 lead in construction standard included specific provisions intended to minimize worker exposure and prevent the transfer of lead to the homes of the workers, such as requirements for decontamination facilities, healthy work practices, the use of personal protective equipment and clothing, and worker training.[8] These provisions constitute the main mechanism through which compliance with air and BLL standards can be achieved and the potential for take home lead can be minimized.

However, the effectiveness of these provisions has yet to be systematically evaluated. For example, Askin and Volkmann[12] showed that work practices and habits such as washing hands after work was associated with lower levels of lead contamination of workers' hands and lower BLLs. High levels of lead contamination have been found in the homes of construction workers,[13] and elevated blood lead levels among the family members of workers exposed to lead have also been reported.[14–16] Among construction workers, high levels of lead contamination of their automobiles, work clothes, and skin was shown to be a significant route of take-home lead exposure.[16–18] The 2005 OSHA review of the lead standard noted that alternative pathways of exposure can be as significant as inhalation exposure, and that noncompliance with the standard pertaining to hygiene facilities and practices was the second most commonly violated section of the standard accounting for 11% of the citations.[11]

In this article our specific objectives were to: (1) measure personal skin, respirator, automobile, and decontamination unit surface contamination of bridge painters working for small contractors, and (2) describe industrial hygiene programs and work and hygiene practices and evaluate their impact on levels of lead contamination. In a companion article in this issue,[19] we present results of airborne lead exposures among bridge painters and of environmental contamination in the vicinity of the work sites.[19]

METHODS

A brief summary of the study is provided here, details of which are described in the companion article.[19] A cross-sectional study of 91 bridge painters from 13 work sites in Massachusetts was conducted over a 2-year period during which sampling for ambient, surface, and skin lead was conducted. Quantitative and qualitative information on the characteristics of the work site, worker activities, work and hygiene practices, and industrial hygiene programs were also gathered through observations and worker interviews.

Sample Collection and Analysis

Rationale for Sample Collection

At the beginning of the work shift, the research team met with workers at a staging area typically located several hundred feet away from the bridge work sites. The staging area housed the decontamination and storage facilities and served as a parking lot for workers' vehicles.

Surface wipe and vacuum samples were collected from the clean and dirty sides of the decontamination unit to evaluate adherence to decontamination procedure and maintenance of the unit. Surface wipe and vacuum samples were also collected from workers' personal vehicles to evaluate their hygiene practices and the potential for take-home lead. After workers changed into work clothing and gathered their personal protective equipment (PPE), we collected wipe samples of their clean respirators to evaluate respirator cleanup and storage. During the work shift, skin wipe samples were collected from workers' hands in the middle of the work shift (at break times) to evaluate the potential for lead ingestion during break activities. At the end of the work shift, workers returned to the staging area where we collected wipe samples of their respirators prior to cleaning and storage to evaluate the proper fit and usage as well as handling of respirators during the work shift.

Once workers had cleaned up and were ready to leave the work site, we collected skin wipe samples from their hands, necks, faces, and arms to evaluate the effectiveness of end of the day washing and cleanup procedures and the potential for ingestion and take-home lead exposure. Because the end of day wipe samples were collected after washing up, the hand wipe samples represent cleaning efficiency of a directly exposed body segment, whereas the face, neck, and arm wipe samples represent indirectly exposed uncovered areas of skin and, hence, demonstrate the thoroughness of the end of day cleanup. All of the surface and skin samples are best thought of as an indicator of the level of contamination and provide a means to evaluate the hygiene facilities and PPE practices rather than representing a human exposure metric.

Skin Wipe Samples

Skin wipe samples were collected from workers on the days they wore air sampling pumps by wiping their skin for 30 sec using Wash'n Dri towelettes (two towelettes from hands and one for each of the other body areas). Upon the instruction and observation of the field IH, hand wipe samples were collected by workers wiping their hands (palm and back) from the top of the wrist to the tip of the fingers. Workers were asked to wipe their necks from ear to ear, to the back of neck, and under the chin down to the top of the Adam's apple. Arm wipe samples were collected by wiping the lower arms from elbow to the wrist, and face wipe samples were collected by wiping the face from forehead to the tip of the chin and sideways from ear to ear.

Wipes were then folded inward and placed into a labeled plastic bag and held for analysis. The skin surface area wiped is different for the various body segments sampled and between individuals; however, this information was not obtainable during sampling. Surface area for the body segments wiped can be estimated based on the mean total body surface area of 1.94 m^2 for an adult male[20] and the fraction represented by the body segments wiped of hands (5%), face (3.5%), neck (2%), and lower arms (6%) from the literature on burn management.[21]

The mean surface area of the body segments of an adult male is then estimated to be: hands 0.097 m^2, face 0.068 m^2, neck 0.039 m^2, and lower arms 0.116 m^2. Midshift (break) and end of shift hand wipe samples were collected from 71% and 75% of workers, respectively, at least once; however, end of shift face, neck, and arm samples were obtained from a much smaller proportion of workers (27%, 27% and 25%, respectively) due to time constraint at the end of the work shift.

Respirator Wipe Samples

Respirator wipe samples were also collected from 70% of workers on the days they wore air sampling pumps. Wipe samples were collected using a series of two Wash 'n Dri towelettes by having the field IH thoroughly wipe the inside of the respirator for 30 sec with each towelette while wearing disposable gloves. The wipes were placed into the same plastic bag and held for analysis.

Respirator wipe samples were collected at two time points: (1) at the beginning of a work shift (representing a clean respirator), and (2) at the end of a work shift (representing a dirty respirator). The cleaning of respirators by workers was not actually observed; therefore, the determination of cleanliness was based on workers' responses to the question about whether respirators had been cleaned before use. Information on the surface area of the respirator wipe samples was not available; however, a majority of the workers used the half facepiece respirator. As noted earlier, the wipe samples are used to indicate the efficacy of the hygiene facilities and PPE practices, and not as a measure of personal exposure.

Worker Vehicle Surface Samples

Vehicle surface samples were collected from less than half (<46%) of workers' personal automobiles using either wipes or vacuum samples. Wipe samples were collected from hard, smooth surfaces (such as car seats and floors) using Wash 'n Dri towelettes by wiping an area of 100 cm^2 using a template (10 cm × 10 cm) as a guide, according to NIOSH Method 9100.[22] Each surface was wiped three times using three to four strokes each time, and the samples were folded and placed into a plastic bag. Wipe samples were collected from steering wheels by wiping the entire steering wheel three times, folding the towelette after each wipe. The steering wheel wipe surface area was not measured during sampling but is estimated to be approximately 1200 cm^2 based on measurements of 10 different models and makes of automobiles.

Vacuum samples were taken from fabric surfaces (such as car seats and floor) by a modified method of Que Hee et al.[23] using a personal air sampling pump calibrated to 3 L/min, a 37 mm diameter, 0.8-μm pore size mixed cellulose ester filter, in a filter cassette with 5-in. tygon tubing attached at the inlet (serving as collection nozzle). A 100 cm^2 area was vacuum sampled using a 10 × 10 cm template as a guide, in slow horizontal and vertical movements.

Decontamination Unit Surface Samples

Surface samples were collected from benches and floors in both the clean and dirty sides of decontamination units by wiping or vacuuming an area of 100 cm^2 using the same protocol described above for worker vehicles. Surface samples were collected from 12 of the 13 decontamination units as one work site obtained their decontamination unit after the completion of our sampling campaign. One decontamination unit did not have separate clean and dirty sides, whereas some did not have benches. Therefore, some sample types were not collected from all the decontamination units.

Analysis

All wipe and vacuum samples were prepared for analysis (i.e., digested) using a modified method of Millson et al.[24] and were analyzed by flame atomic absorption spectrometry using NIOSH Method 7082.[25] Details of the analytical method and quality control issues are described elsewhere.[19]

Characterization of Work Site Hygiene Facilities and Personal Hygiene

In addition to environmental sampling, qualitative information on personal hygiene practices of workers and work site respirator program, hand washing and decontamination facilities was collected on structured field sampling forms through work site observations and interviews with workers (asking pre-set questions). Information on personal hygiene practices was collected through interviews with workers at the end of the shift on days they wore air samplers and/or provided personal skin wipe samples. A total of 82 out of 91 workers (90%) provided some information on: washing hands, showering, or cleaning respirators at the end of the work shift, and washing hands, removing coveralls, and activities during break. Workers provided this information on multiple occasions to reflect the activities on the day they provided a sample.

Information on work site hygiene facilities was gathered on three key provisions of the OSHA lead in construction standard: (1) respirator programs, (2) hand wash facilities, and (3) decontamination (change and shower) facilities through observations during 50 of the 61 visits to the 13 work sites. At each work site, this information was gathered on multiple occasions. The information on personal hygiene and work site hygiene facilities was used to create four indices of good/desirable personal hygiene, respirator, hand wash, and decontamination characteristics by assigning a score of either zero (nondesirable) or one (desirable) to the factors in the indices. The personal hygiene index included information on the six factors reported in Table I; the respirator, decontamination, and hand wash indices were based on 4, 7, and 5 factors, respectively, reported in Table II. Indices were then created by summing all factors and converting them into percent good characteristic or practice. Within each index, scoring was consistent, and equal weight was assigned to all factors. Scores were then categorized as high percent of positive characteristics (≥50%) or low percent of positive

TABLE I. Personal Hygiene Practices of Workers During Bridge Painting

Personal Work Practices and Hygiene Activities[A]	Persons (%) (n/N)[B]	Person-Days (%) (n/N)[C]
Removed coverall at break time	15 (11/73)	13 (18/136)
Break time activities (drink, eat, or smoke)	80 (52/65)	87 (104/120)
Washed hands before break activity	62 (37/60)	68 (69/102)
Smoked cigarettes during work shift	29 (19/66)	29 (37/129)
Wash hands end of day	75 (49/65)	78 (102/130)
Shower end of day	36 (26/72)	38 (53/140)
Clean respirator end of day	57 (41/72)	65 (86/133)

[A] Based on worker responses to questions on the field sampling forms.
[B] Number of workers who responded to the question out of a total of 82 workers who participated in the survey.
[C] Number of person-days on which responses were obtained to the question out of a total of 171 worker-days of survey participation (multiple days per worker).

characteristics (<50%) to evaluate their impact on skin or surface contamination levels.

Statistical Analyses

All statistical analyses were done in PC-SAS version 9.1. Measurement distributions of various sample types were examined through probability plots and were found to be approximately lognormal; hence, they were log-transformed, and geometric means (GM) and geometric standard deviations (GSD) were calculated.

Summary statistics were calculated for the various sample types overall and by job title. The student's t-test was used to compare differences in lead levels on skin, respirators, and surfaces based on the presence or absence of certain personal hygiene activities or work site hygiene characteristics, such as hand washing, showering, cleaning respirator, activities during break, or the work site respirator and decontamination facility characteristics.

Pearson's correlation coefficients were calculated to evaluate relationships among the various sample types, including a subset of paired/matched before and after work respirator wipe samples. Work site respirator program, hand wash, and decontamination facilities and personal hygiene observed during site visits were summarized using frequency distributions. Summary statistics were also calculated for the composite indices of the work site hygiene facilities and personal hygiene.

TABLE II. Work Site Respiratory Program and Hygiene Facilities of Small Contractors During Bridge Painting Projects

Site Characteristics[A]	Site-Days[B] (%) (n/N)
Respirator Program Factors	
Are respirator cartridges available	90 (45/50)
Are respirator parts available	60 (30/50)
Is clean respirator storage available	46 (23/50)
Are respirators cleaned daily	68 (34/50)
Decontamination Facility	
Is the decontamination facility enclosed	94 (47/50)
Is running water and available in the decontamination unit	84 (42/50)
Is hot water available in the decontamination unit	66 (33/50)
Are there showers in decontamination unit	78 (39/50)
Are towels available	44 (22/50)
Is laundry service provided	64 (32/50)
Are personal lockers available	88 (44/50)
Separate Hand Wash Facility	
Is there a separate hand wash facility	62 (31/50)
Are disposable towels available	24 (12/50)
Are cloth towels available	8 (4/50)
Is running water available	36 (18/50)
Is hot water available	8 (4/50)

[A] Based on work site observations recorded on field sampling forms.
[B] Site sampling days (multiple visits per work site).

RESULTS

Work Site Hygiene Facilities and Personal Hygiene Practices

Information on personal hygiene practices and work site hygiene facilities obtained from the field sampling forms are reported in Tables I through III. Information on personal hygiene practices was based on the responses of 82 workers (171 person-days), but not all workers answered all the questions. The findings from questions about personal hygiene practices suggest that some type of break time activity (i.e., drinking, eating, or smoking) was reported for most person-days (87%), and that washing hands before such activity was reported for fewer person-days (68%) (Table I). Respirator cleaning and maintenance was reported for only 65% of person-days; however, the proportion of the day respirators were worn is not known. Only 38% of the person-days included showering, whereas 78% included washing hands at end of shift.

Observed work site characteristics (Table II) were based on 50 work site visits during which the information was collected.

TABLE III. Indices of Work Site Hygiene Facilities, Respiratory Program, and Personal Hygiene

Indices of Work Site and Personal Hygiene	N[A]	Mean (%)	SD	Min	Max
Site Indices					
Respirator program	50	66	33	0	100
Decontamination facility	50	74	29	29	100
Hand wash facility	50	28	27	0	80
Personal Index					
Personal hygiene practices	146	48	29	0	100

[A] Site-days or person-days.

On the remaining 11 work site visits, information on site characteristics was not obtained for a number of reasons related to low level of productivity. As expected, there was generally little variation in the respirator program, decontamination, and hand wash facilities within work site on repeated observations, but greater variation between work sites (data not shown). Likewise, the index of personal hygiene practices (Table III) varied most between work sites, again suggesting that some site- or contractor-related variables determined worker adherence to good practices. This finding underscores the need to assess compliance with the site hygiene provisions of the lead in construction standard. It also suggests that more emphasis should be placed on employers to provide appropriate facilities and opportunities to work safely and develop good work and hygiene practices.

Summary Surface and Skin Levels

Skin Wipe Samples

A summary of skin wipe sample results overall and by job title is presented in Table IV. Measurable levels of lead on hands during breaks were observed for all the job titles. The GMs of hand wipe samples collected during breaks (overall and all job titles except for the foreman) were much higher than at end of shift following cleanup and washup activities. However, these results included some workers who did not wash hands or clean up at then end of the day. The GM wipe level at break was significantly lower for those who reported eating during break than those who did not (503 μg vs. 1054 μg, $t = 2.94$, $p = 0.004$).

Similarly, the GM wipe level at break was lower for those who reported washing hands before break activities compared with those who did not (602 μg vs. 1541μg, $t = 3.68$, $p = 0.0004$). The GM levels of end of shift hand wipe samples by personal hygiene practices and work site hygiene facilities are graphically displayed in Figure 1. These results show that workers at work sites with good decontamination and hand wash facilities indices ($\geq$50% positive characteristics) had lower levels of end of shift hand contamination than those who worked at work sites with lower scores for these indices. Similarly, workers with good hygiene practices such as washing hands or showering at the end of the shift, not smoking, and a high score for personal index ($\geq$50% positive characteristics) had lower levels of lead on their hands than those who did not have good hygiene practices. Most of the differences displayed in Figure 1 were statistically significant (at $p < 0.05$) based on student's t-tests.

Detectable levels of lead were measured from all wipe samples collected from workers' faces, necks, and arms at end of shift, supposedly following cleanup. The numbers of samples were too small and unevenly distributed between the different work site hygiene characteristics or personal hygiene practices to evaluate their impact on exposure levels.

However, Pearson's correlation coefficients showed moderately high correlations ($r \approx 0.7$) between end of shift hand wipe samples and neck or face wipe samples, and between face and neck wipe samples. Arm wipe samples were not correlated with any other skin wipe samples collected at the end of the

TABLE IV. Personal Skin Wipe Lead Levels by Job Title

	Hand Wipes–Break (μg/Skin Surface)[B]			Hand Wipes[A] (μg/Skin Surface)[B]			Face Wipes[A] (μg/Skin Surface)[B]			Neck Wipes[A] (μg/Skin Surface)[B]			Arm Wipe[A] (μg/Skin Surface)[B]		
Job Title	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**
Overall	108	814	3.7	88	383	4.3	25	373	2.0	25	455	2.5	23	381	2.6
Blaster	28	1192	2.9	22	447	3.7	6	488	1.6	6	777	3.2	6	436	1.9
Foreman	2	147	1.1	4	338	6.2	2	194	1.5	2	209	1.0	2	257	5.8
Laborer	64	766	3.9	50	364	4.9	16	371	2.2	16	435	2.2	15	380	2.7
Owner	1	522	—[C]	1	97	—	—	—	—	—	—	—	—	—	—
Painter	1	481	—	—[D]	—	—	—	—	—	—	—	—	—	—	—
Pressure washer	8	617	5.3	4	212	2.5	—	—	—	—	—	—	—	—	—
Supervisor	4	768	3.4	7	616	3.4	1	297	—	1	179	—	—	—	—

Note: ANOVA for Site, F statistics = 18.79, $p < 0.0001$.

[A] End of day wipe samples after shower and/or hand wash or cleanup.

[B] Estimated surface area for the body segments include: hands 0.097 m,^{2} face 0.068 m,^{2} neck 0.039 m,^{2} and lower arms 0.116 m.^{2}

[C] GSD could not be calculated for sample size of 1 or 0.

[D] Samples not collected.

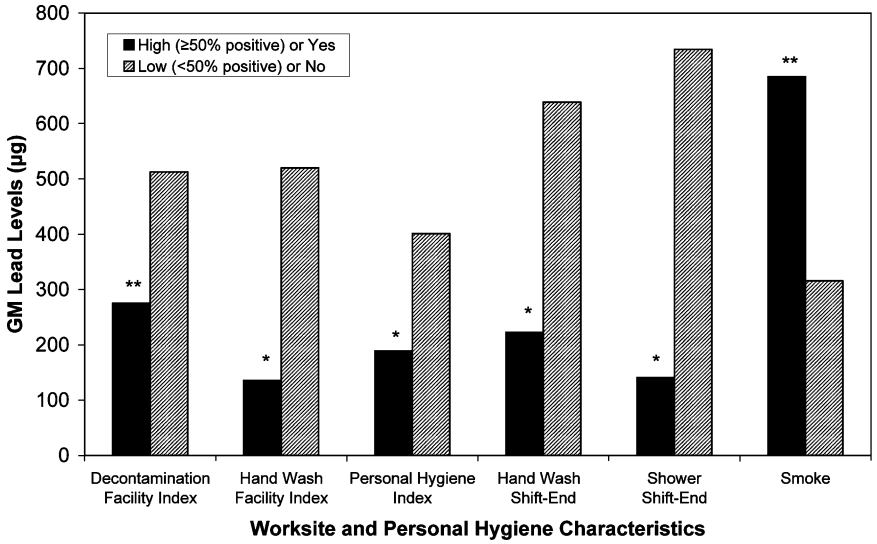

FIGURE 1. Geometric mean hand wipe lead levels by personal hygiene and work site hygiene facilities. *Significant differences at $p < 0.05$ level. **Significant differences at $p < 0.1$ level.

work shift. Break time hand wipe samples were moderately correlated ($r = 0.51$) with end of shift hand wipes but not with any other skin wipe sample types.

Respirator Wipe Samples

A summary of respirator wipe sample results collected at the beginning and end of shift, overall, and by job title, is reported in Table V. The GMs of respirator wipes before work were similar among job titles except for the job titles of Owner and Painter. The highest GM lead levels collected at end of shift were for the job titles of Foreman, Owner, Pressure Washer, and Supervisor—jobs generally perceived to have lower exposures. These results indicate significant levels of lead deposited inside the respirator, clearly suggesting that respirators were not properly maintained despite the fact that 57% (41/72) of workers reported cleaning their respirators (on at least one day) at the end of the shift on the day of sampling.

TABLE V. Respirator Wipe Lead Levels by Job Title

	Respirator Wipe-Before Work (µg/Respirator Surface)			Respirator Wipe-After Work (µg/Respirator Surface)		
Job Title	**N**	**GM**	**GSD**	**n**	**GM**	**GSD**
Overall	85	143	3.3	91	286	3.1
Blaster	22	151	3.5	23	225	2.4
Forman	2	139	1.3	3	964	1.7
Laborer	49	151	3.1	53	278	3.3
Owner	2	16	3.1	1	509	—
Painter	1	406	—[A]	—[B]	—	—
Pressure Washer	5	159	4.8	4	548	5.2
Supervisor	4	118	1.2	7	301	3.0

Note: ANOVA for Site, F statistics = 12.15, $p < 0.0001$.
[A]GSD could not be calculated for sample size of 1 or 0.
[B]Samples not collected.

The GM levels of respirator wipes by work site hygiene characteristics and personal hygiene practices are also shown in Figure 2. The GM respirator wipe levels at the beginning of work shift were significantly lower for those who reported cleaning their respirator, had a high personal index score, and who worked on work sites with high respirator and decontamination index scores than those who did not, based on student's t-test. A similar trend was observed for respirator wipe levels at end of shift, and all but one of the differences (respirator index) were statistically significant. For a subset of $n = 47$ matched beginning and end of shift respirator wipe samples collected on the same respirator, a significant correlation $r = 0.75$ was observed. However, only moderate correlation was observed with either end of shift hand wipes ($r = 0.24$–0.46) or break time hand wipes ($r = 0.53$–0.59) and beginning and end of shift respirator wipes, respectively.

Personal Automobile Wipe and Vacuum Samples

Table VI summarizes the results of lead contamination of workers' personal automobiles. The degree of contamination inside automobiles was high, with all vacuum and wipe samples from all areas of the automobile having detectable levels of lead. The highest GM levels were measured on the floors, followed by car seats and steering wheel (after dividing the steering wheel results by 12 to normalize them to 100 cm^2).

The GM levels of automobile contamination by work site hygiene characteristics and personal hygiene practices are shown in Figure 3. The GM steering wipe levels were lower for those who reported washing their hands or showering at

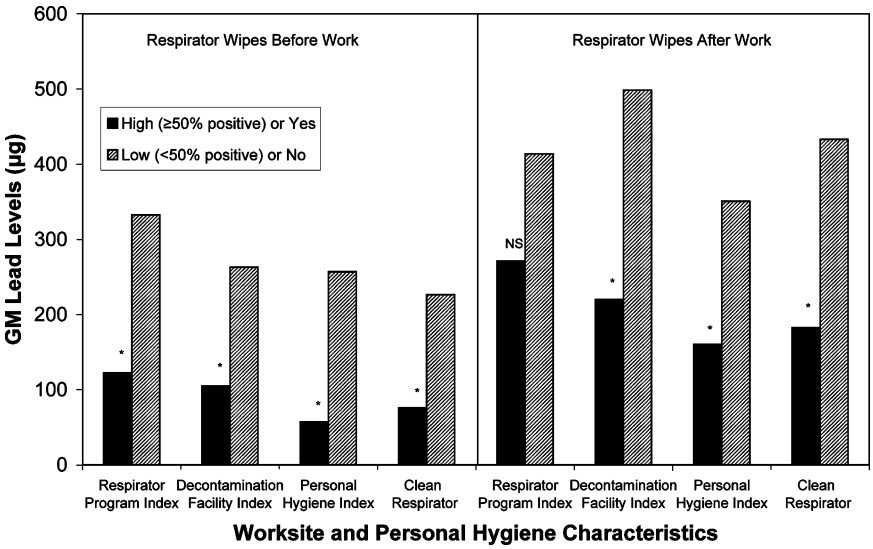

FIGURE 2. Geometric mean respirator wipe lead levels by personal hygiene and work site hygiene facilities. *Significant differences at $p < 0.05$ level. NS, differences not statistically significant.

end of shift, had higher personal index scores, and worked at work sites with higher decontamination and hand wipe index scores; all were statistically significant except for showering and hand wipe index.

The number of wipe and vacuum samples from car seats and floors was too small for conducting stratified analysis by work site hygiene characteristics and personal hygiene practices, often giving inconsistent results. The steering wheel wipe samples had moderately high correlations with the car seat and floor wipe samples ($r \approx 0.7$) but not with car seat and floor vacuum samples. In addition, the car seat and floor vacuum samples had a correlation of $r = 0.63$, whereas the car seat and floor wipe samples had correlation of $r = 0.95$. Furthermore, contrary to expectation, end of shift hand wipe levels were not correlated with steering wipe levels and only moderately correlated with car seat wipe levels ($r = 0.49$).

Decontamination Unit Wipe and Vacuum Sampling

Results of the side-by-side vacuum and wipe samples taken from two locations in the clean and dirty sides of the decontamination unit are reported in Table VII. As expected, the dirty side of the decontamination unit had higher levels of lead; however, the clean side also had significant levels of contamination on floors, and to a lesser degree on benches. The GM lead levels on the surface samples (floors and benches) collected from the clean side of the decontamination unit were greater

TABLE VI. Personal Vehicle Surface Lead Levels by Job Title

	Vehicle Floor–Vacuum (μg/100 cm^2)			Vehicle Floor–Wipe (μg/100 cm^2)			Vehicle Seat–Vacuum (μg/100 cm^2)			Vehicle Seat–Wipe (μg/100 cm^2)			Vehicle Steering–Wipe (μg/Surface)[A]		
Job Title	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**	**n**	**GM**	**GSD**
Overall	27	168	4.1	14	88	4.8	28	68	5.3	15	70	4.3	42	142	4.2
Blaster	6	125	4.1	2	10	2.0	8	48	5.9	3	54	3.8	11	111	4.9
Forman	1	1018	—[B]	—[C]	—	—	—	—	—	1	154	—	1	959	—
Laborer	14	169	4.1	7	118	5.1	12	54	4.5	10	66	5.2	20	137	3.7
Owner	1	64	—	—	—	—	1	12	—	—	—	—	1	70	—
Pressure Washer	1	757	—	2	90	7.3	—	—	—	1	134	—	2	41	14.0
Supervisor	4	141	5.4	3	184	1.4	7	192	5.0	—	—	—	7	277	3.2

Note: ANOVA for Site, F statistics = 3.26, p = 0.0007.
[A] Surface area of steering wheel was estimated to be 1200 cm^2 based on a sample of 10 vehicles.
[B] GSD could not be calculated for sample size of 1 or 0.
[C] Samples not collected.

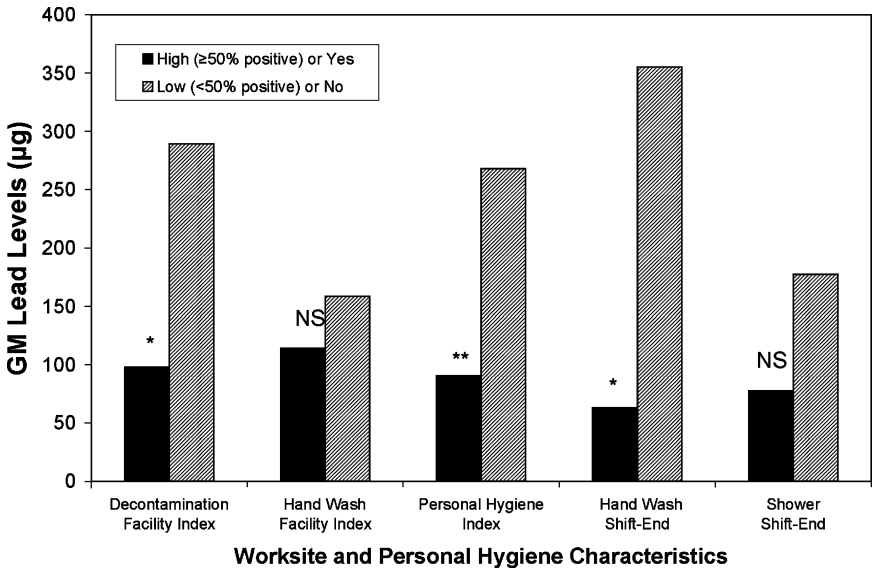

FIGURE 3. Geometric mean personal vehicle steering wheel wipe lead levels by personal hygiene and work site hygiene facilities. *Significant differences at $p < 0.05$ level. **Significant differences at $p < 0.1$ level. NS, differences not statistically significant.

than the OSHA recommended guideline of 21.5 μg/100 cm^2 (200 μg/ft^2)[26] for evaluating cleanliness of change areas, storage facilities, and lunchrooms/eating areas, and much greater than the Housing and Urban Development (HUD) and Environmental Protection Agency (EPA) clearance guidelines of 4.3 μg/100 cm^2 (40 μg/ft^2)[27,28] for floors. Although GM levels of wipe samples were higher than GM levels of vacuum samples, the differences were not statistically significant. Additionally, the vacuum sample results were highly variable with GSD in the range of 9–33.

DISCUSSION

Skin Exposures and Blood Lead Levels

In this study, we measured large amounts of lead deposited on workers' skin (hands, necks, faces, and arms). Lead on workers' skin has also been reported in other studies. For example, NIOSH[16] reported hand and face wipe levels in the ranges of 1–920 μg and 4–260 μg, respectively, among those who washed, and 4–5600 μg and 4–1800 μg, respectively, among those who did not wash prior to wipe sample collection.

Askin and Volkmann[12] reported a significant association between BLLs and levels of lead on the hands of workers. The authors suggested three plausible mechanisms by which lead on workers' hands could enter the body: (1) via ingestion from hand-to-mouth transfer; (2) via direct entry into the bloodstream when the skin barrier is compromised; and (3) via percutaneous absorption of inorganic lead through skin, sweat glands, or hair follicles. Note that the role, if any, of this third pathway is unclear.

The potential for ingestion of lead among construction workers has been reported in other studies, identifying the hand-to-mouth activity as the main route of exposure.[29] In this study, lead was measured on all workers' hands before eating, regardless of hand washing before break activity. These data strongly suggest that skin contamination among these bridge workers can be an important source of lead ingestion and absorption.

TABLE VII. Decontamination Unit Surface Lead Levels by Surfaces Sampled

	Wipe (μg/100 cm^2)				Vacuum (μg/100 cm^2)			
Sample Area	**N**	**AM**	**GM**	**GSD**	**N**	**AM**	**GM**	**GSD**
Decontamination unit Clean side bench	16	184	77	4.0	10	209	31	9.0
Decontamination unit Clean side floor	17	748	211	6.8	16	1041	60	16.8
Decontamination unit Dirty side bench	13	2380	347	9.6	10	15,268	277	33.2
Decontamination unit Dirty side floor	15	1639	539	4.9	15	4928	194	18.7

Notes: ANOVA for Site Vacuum, F statistics = 5.46, $p < 0.0001$; ANOVA for Site Wipe, F statistics = 6.46, $p < 0.0001$.

Work Site Hygiene Facilities and Personal Hygiene Practices

Healthy work practice is an important element for minimizing worker exposure to lead and for reducing the likelihood of take-home lead exposure. Observations of personal hygiene practices in this study show a significant fraction of person-days during which important hygiene practices were not present, such as washing, showering, and cleaning respirators at the end of the shift.

Similar results have been reported by other researchers. In a study of construction tradesmen working on projects with potential lead exposure, Reynolds et al.[4] observed that only 19% of the workers reported wearing coveralls; 19% reported using changing facilities; 61% reported using hands/face washing facilities; 15% reported using showers, 39% reported eating at a separate facility; 8–64% reported washing before eating, drinking, or smoking; 36% reported smoking; and 25% reported biting their nails.

Lack of healthy work practices may also impact BLLs. For example, among workers at a lead processing facility, Askin and Volksmann[12] reported that, generally, workers who had low BLLs also had cleaner work clothes and shoes, reported washing hands after work, and had less lead on their hands.

Our data also suggest that at most work sites, an effective respirator program was not in place. Although parts and supplies were generally available, a proper storage facility and cleaning and maintenance of respirators were lacking. Overall, respirators were stored in the company trucks at 27% of worker sites, in the decontamination unit at 50% and in offices at 23% of the work sites (data not shown). It is noteworthy that even among workers who reported cleaning their respirators, the GM level of before work wipe samples was 76 μg. As expected, the overall GM level of pre-shift respirator wipes was significantly lower than the post-shift level because pre-shift wipes were collected after respirators were supposedly cleaned, and post-shift wipes were collected at end of shift before cleaning had taken place.

However, the high before-work respirator wipe levels suggests that respirators either were not cleaned thoroughly or were not stored in a clean location. High, end of shift respirator wipes suggest poor respirator fit during use, removal during tasks, or improper storage and handling during the work shift.

Reynolds et al.[4] evaluated work habits of construction workers through questionnaires and found a high percentage of construction workers (88%) reporting respirator use, but only 20% with potential lead exposure were fit tested. Johnson and colleagues[18] also found an absence of respirator programs, infrequent maintenance and cleaning of the respirators, and respirators left uncovered between tasks.

We observed similar patterns of respirator use and maintenance. Because respirators may be required for most surface preparation tasks to bring exposures below the PEL,[19] this observation is of concern; lack of a functioning respirator program, improper respirator use and fit, and respirator contamination together could cause a significant inhalation exposure for these workers.

Compliance with many provisions of the lead in construction standard was poor. The site characteristics indices suggest that fully functioning hand washing and decontamination facilities and respirator programs were not available at many work sites. Thus, in conjunction with providing worker training on the importance of following safe work practices and adhering to proper hygiene practices and respirator maintenance, contractors should be required to provide all appropriate facilities in functioning order and should take into consideration time needed to clean up at the end of the workshift and to maintain respirators during the work shift. Reynolds et al.[4] found that 81% of tradesmen working on projects with potential lead exposures reported that employers did not provide any decontamination facilities (i.e., work clothing, changing or washing facilities) despite the requirements of the OSHA lead standard.

Our results also suggest that some jobs titles perceived to have lower airborne lead exposures were consistently associated with higher contamination levels of their automobiles and respirators. Similar results have been observed by Piacitelli et al.[17] who observed that good hygiene and work practices were followed by workers in the high-exposure category, but only 25% of workers in the low-exposure category reported wearing company-supplied work clothes and changing clothes or showering at the end of the shift.

Our results further suggest that bridge painters are exposed to airborne lead exposures above the PEL during most surface preparation and painting tasks; therefore, provisions of the lead in construction standard (decontamination, respirator use, etc.) need to be applied to all workers at these small contractor work sites not just to selected workers thought to have higher airborne lead exposures. These conclusions are supported by the observation that the highest levels of lead contamination in this study were found in the personal vehicles of the foreman, supervisor, and pressure washer; jobs generally presumed to have lower airborne exposures. Similar findings were reported by Piacitelli et al.,[17] who measured the highest levels of lead in personal vehicles of on-site industrial hygienists and the lowest levels in personal vehicles of abrasive blasters (associated with the highest airborne lead exposures).

The short duration and temporary nature of these bridge painting projects, especially among small contractors, may make it difficult to implement provisions of the standard, such as having a functioning decontamination facility. However, when provisions of the standard are properly implemented, significant reduction in BLLs can be achieved and the problem of lead poisoning among deleaders and bridge painters mitigated. For example, a study by Levin and colleagues[9] evaluated the impact of well-implemented provisions of the lead in construction standard on BLL of ironworkers renovating a large lead-painted steel bridge. They demonstrated significant decline in baseline and maximum BLL attributed, in general, to improvements in engineering controls, enhancement of the respirator program, introduction of decontamination facilities, ambient and medical monitoring requirements, all stemming from the new standard.

A demonstration project undertaken by the Connecticut Road Industry Surveillance Project (CRISP) also showed significant decline in BLL among workers on bridge projects attributed to the implementation of many of the provisions of the lead in construction standard in addition to their key feature of specifying these health and safety requirements in the contracts with the bridge work contractors.[6]

Take-Home Lead

Lead can be carried into the homes of the workers on clothing, skin, and hair and in automobiles.[16] The lead in construction standard includes specific provision to prevent the transfer of lead from the work site to the homes of workers, such as requirements for decontamination facilities, work clothes, washing or showering facilities.

Data from the present study suggest a high probability of take-home lead through contaminated skin and automobiles. Although hair and clothing samples were not collected in this study, evidence from questionnaires and observations suggests that hair and clothing was likely contaminated, with low frequencies of showering (38%) and washing (79%) at end of day. It is noteworthy that end of shift skin wipe levels among those who reported washing hands (GM: hands = 223 μg) or showering (GM: hands = 141 μg) were still high. Hence, the decontamination procedure does not appear to fully remove lead from workers' skin. Similar results have been reported by NIOSH[16] who showed mean levels of lead on workers hands after end of shift washing procedures as 84 μg for blasters, 64–65 μg for operators and apprentices, and 5–6 μg for inspectors and industrial hygienists.

Johnson et al.[18] reported lead levels in the range of 1–90 μg/100 cm^2 (data converted from μg/m^2) in the automobiles of various trades workers who had worked on a previously deleaded bridge. Piacitelli et al.[17] also reported lead contamination in workers' automobiles, with the highest GM levels on the drivers' floors (GM = 19 μg/100 cm^2, data converted from μg/m^2). They also found a significant correlation between lead contamination levels on the steering wheels of workers' automobiles and BLLs (r = 0.54). The overall mean levels of automobile contamination observed in this study were comparable to those reported by others.[16,17] In fact, one surface sample collected from a child's car seat in one worker's personal automobile had 108 μg lead/100 cm.^{2}

In the present study, we measured high levels of lead on surfaces in the clean sides of decontamination trailers using two types of sampling (wipes and vacuum). This study, as others, reported a high degree of correlation between sample types and observed higher GM levels of lead obtained by wipe samples compared with vacuum samples.[30,31] Although no federal guidelines exist for evaluating lead on surfaces or skin in occupational environments, HUD/EPA recommend a clearance standard of 4.3 μg lead/100 cm^2 (40 μg/ft^2) in surface dust on floors.[27,28] OSHA suggests a level of 200 μg/ft^2 (based on an older HUD clearance level) in their directive CPL 2–2.58 issued in 1993 regarding inspection and citation guidelines for hygiene facilities and practices to evaluate wipe samples collected from change areas, storage facilities, and/or lunchrooms/eating areas.[26]

For comparison, the GM lead concentrations on all floor surface samples from the clean side of decontamination units in this study were above this level. Jarrett[32] reported surface wipe levels from various surfaces in the clean side of the locker room in the range of 9–75 μg/100 cm^2 (data converted from μg/ft^2) at a work site conducting abrasive blasting of a crane. Levels from different locations in the lunch and tool room ranged from 69–420 μg/100 cm^2 (data converted from μg/ft^2). This observation provides additional evidence that lead may be carried away from the work site on non-work shoes stored in the clean side of the decontamination trailer, and potentially taken to all areas of workers' homes.

Training of contractors and employees may provide one approach to mitigate the hazards of lead exposure among bridge painters and their potential for take-home lead. Studies have reported selected and modest improvements in work practices among contractors and employees trained in lead-safe work methods that were retained over the long term.[33–36] However, unfamiliar methods or work methods that were costly or reduced quality or productivity were not adopted. Therefore, a comprehensive approach is required for intervention to be effective, and may include: enforcement, contractual requirements, and public health surveillance in addition to training.

Limitations of the Study

Whereas this study provides useful information on compliance, or lack thereof, with certain aspects and provisions of the lead in construction standard, there are some uncontrollable limitations of the study that need to be addressed. Some workers did not respond to all the questions regarding hygiene practices partly due to lack of time at the end of the shift but possibly due to social stigma associated with not following hygiene practices. So it is possible that those who did not respond to the questions also did not have good hygiene practices. It is also likely that some workers gave responses that are socially more acceptable instead of acknowledging not having good hygiene practices. Both these situations will likely bias the results and suggest that hygiene practices are better than they really are. Because a validation/reliability study was not conducted, it is not possible to estimate the extent of this bias if it exists. Adequate evidence already exists to suggest that improvements are needed in personal hygiene practices, so the bias will not impact on the conclusions of this study. The skin and surface wipe levels are simple measures used to evaluate certain aspects of the hygiene and PPE practices and facilities and should not be considered as estimates of personal exposure.

CONCLUSION

The data presented here show high degree of surface and skin contamination and suggest that skin exposure may be an important pathway of lead exposure among these construction workers. There is also a strong suggestion that lead

may be transported to the workers' homes via contaminated skin, clothing, and automobiles. A number of provisions of the OSHA lead in construction standard aimed at preventing lead ingestion and minimizing take-home exposures were poorly followed. Hence, there are significant opportunities for improving work site hygiene facilities (such as decontamination and hand wash facilities), respirator programs, and worker hygiene practices.

In addition, further evaluation of decontamination procedures is needed to ensure complete removal of lead from the skin after washing or showering. In our companion article, we also show significant opportunities to reduce worker exposure and environmental contamination via instituting engineering controls and improving the containment structure.

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REFERENCES

1. **Centers for Disease Control and Prevention (CDC):** Adult blood lead epidemiology and surveillance–United States, 2002. *MMWR 53*(26):578–582 (2004).
2. **National Institute for Occupational Safety and Health (NIOSH):** *Protecting Workers Exposed to Lead-Based Paint Hazards*. DHHS (NIOSH) Publication No. 98–112. Cincinnati, Ohio: NIOSH, 1997.
3. **Reynolds, S.J., L.J. Fourtes, R.L. Garrels, P. Whitten, and N.L. Sprince:** Lead poisoning among construction workers renovating a previously deleaded bridge. *Am. J. Ind. Med. 31*:319–323 (1997).
4. **Reynolds, S.J., R. Seem, L.J. Fourtes, et al.:** Prevalence of elevated blood leads and exposure to lead in construction trades in Iowa and Illinois. *Am. J. Ind. Med. 36*:307–316 (1999).
5. **Tumpowsky, C.M., L.K. Davis, and R. Rabin:** Elevated blood lead levels among adults in Massachusetts, 1991–1995. *Public Health Rep. 115*(4):364–369 (2000).
6. **Vork, K.L., S.K., Hammond, J. Sparer, and M.R. Cullen:** Prevention of lead poisoning in construction workers: A new public health approach. *Am. J. Ind. Med. 39*:243–253 (2001).
7. **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Alert, Request for Assistance in Preventing Lead Poisoning in Construction Workers*. DHHS (NIOSH) Publication No. 91–116a. Cincinnati, Ohio: NIOSH, 1992.
8. Occupational Safety and Health (OSHA), United States Department of Labor, "Regulations (Preambles to Final Rules) Lead Exposure in Construction." 29 CFR 1926. 1993.
9. **Levin, S.M., M. Goldberg, and J.T. Doucette:** The effect of the OSHA Lead Exposure in Construction Standard on blood lead levels among iron workers employed in bridge rehabilitation. *Am. J. Ind. Med. 31*:303–309 (1997).
10. **Massachusetts Division of Occupational Safety:** *Lead at Work: Elevated Blood Lead Levels in Massachusetts Workers, 1996–2001*. Occupational Health Surveillance Program, Massachusetts Department of Public Health, 2005.
11. "Regulatory Review of 29 CFR 1926.62, Lead in Construction." [Online] Available at: http://osha.gov/dea/lookback/lead-construction-review.html (Accessed June 2008).
12. **Askin, P.D.P., and M. Volkmann:** Effect of personal hygiene on blood lead levels of workers at a lead processing facility. *AIHAJ 58*:752–753 (1997).
13. **Piacitelli, G.M., E.A. Whelan, W.K. Sieber, and B. Gerwel:** Elevated lead contamination in homes of construction workers. *Am. Ind. Hyg. Assoc. J. 58*(6):447–454 (1997).
14. **Whelan, E.A., G.M. Piacitelli, B. Gerwel, et al.:** Elevated blood lead levels in children of construction workers. *Am. J. Publ. Health 87*(8):1352–1355 (1997).
15. **Gerson, M., S.K. Van Den Eeden, and P. Gahagan:** Take home lead poisoning in a child from his father's occupational exposure. *Am. J. Ind. Med. 29*:507–508 (1996).
16. **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazards Evaluation Report (HETA-93-0512-2503), George Campbell Painting Company, Groton, Connecticut,* April 1995.
17. **Piacitelli, G.M., E.A. Whelan, L.M. Ewers, and W.K. Sieber:** Lead contamination in automobiles of lead-exposed bridgeworkers. *Appl. Occup. Environ. Hyg. 10*:849–855 (1995).
18. **Johnson, J.C., S.J. Reynolds, L.J. Fuortes, and W.R. Clarke:** Lead exposure among workers renovating a previously deleaded bridge: Comparisons of trades, work tasks. *AIHAJ 61*:815–819 (2000).
19. **Virji, M.A., S.R. Woskie, and L. Pepper:** Task-based lead exposures and work site characteristics of bridge surface preparation and painting contractors. *J. Occup. Environ. Hyg. 6*:99–112 (2009).
20. **Environmental Protection Agency (EPA):** *Exposure Factors Handbook, Volume I—General Factors*, Chapter 6 Dermal Route (EPA/600/P-95/002Fa). Washington, D.C.: National Center for Environmental Assessment, Office of Research and Development, 1997.
21. **Wolf, S.E., and B.A. Pruitt:** Burn management. In *Irwin and Rippe's Intensive Care Medicine*, 6th Edition, R.S. Irwin and J.M. Rippe (eds.). Philadelphia: Lippincott Williams and Wilkins, 2008. pp. 1930–1937.
22. **National Institute for Occupational Safety and Health (NIOSH):** NIOSH Method 9100: Lead by FAAS. In *NIOSH Manual of Analytical Methods*, 4th Edition, DHHS (NIOSH) Pub. No. 94-113. Cincinnati, Ohio: NIOSH, 1994.
23. **Que Hee, S.S., B. Peace, C.S. Clark, et al.:** Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. *Environ. Res. 38*:77–95 (1985).
24. **Millson, M., P.M. Eller, and K. Ashley:** Evaluation of wipe sampling materials for lead in surface dust. *Am. Ind. Hyg. Assoc. J. 55*:339–342 (1994).
25. **National Institute for Occupational Safety and Health (NIOSH):** NIOSH Method 7082: Lead by FAAS. In *NIOSH Manual of Analytical Methods*, 4th Edition, DHHS (NIOSH) Pub. No. 94-113. Cincinnati, Ohio: NIOSH, 1994.
26. "OSHA Directives CPL 2–2.58, Lead Exposure in Construction." 29 CFR, Parts 1926.62 Interim Final Rule—Inspection and Compliance Procedures, 1993.
27. "Lead Safe Housing Rule." 24 CFR Part 35 Subpart R – Methods and Standards for Lead-Paint Hazard Evaluation and Hazard Reduction Activities, 1999.
28. "Lead; Identification of Dangerous Levels of Lead; Final Rule." 40 CFR, Parts 745, 2001.
29. **Levin, S.M., and M. Goldberg:** Clinical evaluation and management of lead-exposed construction workers. *Am. J. Ind. Med. 37*(1):23–43 (2000).
30. **Clark, C.S., R.L. Bornschein, W. Pan, et al.:** An examination of the relationships between the U.S. Department of Housing and Urban Development floor lead loading clearance level for lead based paint abatement, surface dust lead by a vacuum collection method, and pediatric blood lead. *Appl. Occup. Environ. Hyg. 10*:107–110 (1995).

31. **Reynolds, S.J., L. Etre, P.S. Thorne, P. Whitten, M. Selim, and W.J. Popendorf:** Laboratory comparison of vacuum, OSHA and HUD sampling methods for lead in household dust. *AIHAJ 58*:439–446 (1997).
32. **Jarrett, C.:** Evaluation of elevated blood lead in a commercial painter. *Appl. Occup. Environ. Hyg. 18*:808–811 (2003).
33. **Buzzetti, A.J., F. Greene, and D. Needham:** Impact of a lead-safe training program on workers conducting renovation, painting, and maintenance activities. *Public Health Rep. 120*(1):25–30 (2005).
34. **Harrington, D., P. Scholz, G. Lomax, H. Stahlschmidt, J. Vannoy, and B. Materna:** Can half-day trainings motivate small contractors to address lead safety? *Health Promot. Pract. 5*(3):297–305 (2004).
35. **Sterling, D.A., R.D. Lewis, F. Serrano, K. Dugbatey, R.G. Evans, and L.S. Sterling:** Lead abatement training for underserved populations: Lessons learned. *Appl. Occup. Environ. Hyg. 15*:217–27 (2000).
36. **Materna, B.L., D. Harrington, P. Scholz, et al.:** Results of an intervention to improve lead safety among painting contractors and their employees. *Am. J. Ind. Med. 41*(2):119–130 (2002).