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Task-Based Lead Exposures and Work Site Characteristics of Bridge Surface Preparation and Painting Contractors

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This study of bridge painters working for small contractors in Massachusetts investigated the causes of elevated blood lead levels and assessed their exposure to lead. Bridge work sites were evaluated for a 2-week period during which personal and area air samples and information on work site characteristics and lead abatement methods were gathered. Short-duration personal inhalable samples collected from 18 tasks had geometric means (GM) of 3 $\mu\text{g}/\text{m}^3$ to 7286 $\mu\text{g}/\text{m}^3$. Full-shift, time-weighted average (TWA) inhalable samples (≥ 6 hours) collected from selected workers and work sites had GMs of 2 $\mu\text{g}/\text{m}^3$ to 15,704 $\mu\text{g}/\text{m}^3$; 80% of samples exceeded the permissible exposure limit (PEL) of 50 $\mu\text{g}/\text{m}^3$, on average by a factor of 30. Area inhalable samples collected from three locations ranged from 2 $\mu\text{g}/\text{m}^3$ to 40,866 $\mu\text{g}/\text{m}^3$ from inside the containment, 2 $\mu\text{g}/\text{m}^3$ to 471 $\mu\text{g}/\text{m}^3$ from a distance of < 6 meters, and 2 $\mu\text{g}/\text{m}^3$ to 121 $\mu\text{g}/\text{m}^3$ from > 6 meters from the containment. Seventy nine percent of the area samples from inside the containment exceeded the PEL on average by a factor of 140. Through observations of work site characteristics, opportunities for improving work methods were identified, particularly the institution of engineering controls (which were only occasionally present) and improvement in the design and construction of the containment structure. The high levels of airborne lead exposures indicate a potential for serious exposure hazard for workers and environmental contamination, which can be mitigated through administrative and engineering controls. Although these data were collected over 10 years ago, a 2005 regulatory review by the Occupational Safety and Health Administration (OSHA) of its lead in construction standard reported that elevated lead exposures and blood lead levels, high occurrence of noncompliance with the lead standard, and nonimplementation of newer technology especially among small painting firms employing < 10 workers are still widespread. As a result, the findings of this study are still quite germane even a decade after the introduction of the new OSHA standard.

Keywords bridge painting, construction industry, inhalable exposure, lead exposure assessment, task-based sampling

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INTRODUCTION

Airborne lead exposure above the Occupational Safety and Health Administration's (OSHA) permissible exposure limit (PEL) have historically occurred in many occupations, especially in the construction industry where exposures frequently exceeded the contemporary PEL (200 $\mu\text{g}/\text{m}^3$) by orders of magnitude.^(1–3) In 1993, the new OSHA lead in construction standard (29 CFR 1926.62) came into effect, which lowered the PEL to 50 $\mu\text{g}/\text{m}^3$ and also contained additional mandates to ensure worker protection from health hazards of lead.⁽⁴⁾ Since the implementation of this standard, the few studies that have reported on lead exposures among construction painters continue to show airborne exposures well in excess of the PEL.^(5–11)

In 2005, OSHA conducted a regulatory review of the lead in construction standard to determine whether revisions to the standard were needed.⁽¹²⁾ The review concluded that retention of the standard was necessary for continued worker protection, especially for bridge painters and deleaders who can experience lead exposures in excess of 50,000 $\mu\text{g}/\text{m}^3$ during abrasive blasting in containment without adequate ventilation, high blood lead levels, and instance of noncompliance with the lead standard.

Analysis of the OSHA IMIS data suggests that construction workers employed by small contractors (< 10 employees) experience higher levels of median lead exposures than workers employed by larger businesses.⁽¹³⁾ The 2004 U.S. census of all painters (NAICS 23832) estimated that small businesses employing < 20 workers constitute 95% of the establishments involved in painting, employing 56% of the work force in this classification.⁽¹⁴⁾ The 2006 census data for Massachusetts show that a majority of the state's 1697 nonresidential painters (NAICS 238322) are employed by small contractors and are potentially exposed to lead.⁽¹⁵⁾

Whereas the most recent data from the state's Occupational Lead Registry for the period (1996 to 2001) show a 41% decline in the number of cases of elevated blood lead levels (defined as > 25 $\mu\text{g}/\text{dL}$) from the earlier period (1991 to 1995),

elevated blood lead levels continue to occur, especially among construction workers.⁽¹⁶⁾ Construction painters and deleaders constitute 77% of the workers in the registry with blood lead levels >40 $\mu\text{g}/\text{dL}$.⁽¹⁶⁾

The overall objective of this research project was to examine the extent to which a wide variety of factors (ranging from lead removal methods and engineering controls to social, behavioral, beliefs, and attitudes) affect blood lead levels, airborne, skin, and surface lead exposures of painters working for small contractors where few studies have been conducted. In this study, specific objectives were to: (1) identify and monitor tasks performed by bridge painters working for small contractors, (2) measure full-shift personal and area airborne lead exposures at these work sites, (3) describe work site characteristics and their impact on airborne exposure levels, and (4) evaluate the association between inhalable and total or respirable lead exposures at these work sites. In a companion article published in this issue, we present the results of individual work practices, work site hygiene facilities and programs, and their impact on skin and surface lead contamination, which remains a significant but poorly understood pathway of worker and family exposure through ingestion and take-home lead, respectively.⁽¹⁷⁾

METHODS

Study Overview

A cross-sectional study of 91 bridge painters from 13 work sites in Massachusetts was conducted over a 2-year period from 1994 to 1995. Each work site was evaluated for 2 weeks during which biological monitoring for blood lead and environmental sampling for airborne, surface, and skin lead contamination was conducted. Quantitative and qualitative information on the characteristics of the work site, worker activities and work practices, industrial hygiene programs, and lead abatement methods were gathered. Workers were requested to fill out activity-time diaries at the end of every workday in which they recorded the tasks performed, the duration of each task, and the type of respirator used during the task.

Description of Work Sites

Contractors who were awarded bridge repainting contracts by the Massachusetts Highway Department were invited to participate in the study. A total of 8 contractors working at 13 work sites volunteered to participate in the study, which began 1 year after the new OSHA lead in construction standard was implemented. These were small contractors with a typical work crew of 6 workers (range 2 to 11 workers on any given workday). Eleven of the work sites were roadway overpasses over major highways and secondary roads; at these locations work was done on temporary platforms raised from the ground up. The remaining two work sites were bridges over rivers; at these sites work was done on platforms that were suspended from the steel rails of the bridge above.

Bridge surface preparation was conducted inside containment structures designed to minimize lead emission to the

environment. The containment structures varied from fully enclosed structures with negative pressure ventilation erected for abrasive blasting to partially enclosed structures erected for painting tasks after the removal of old paint. The containment structure and platforms were moved across the span of the bridge as work was completed in one section and progressed to the next. Work on bridge railings was usually conducted in the open without any containment structure. On busy roads with heavy daytime traffic, work was conducted on the night shift typically from 7 p.m. to 5 a.m. On smaller secondary roads, work was conducted during the day shift typically from 7 a.m. to 3 p.m.

Description of the Work Process

For small contractors, the process of bridge surface preparation and painting involves a daily routine (sequence) of several stages. The process begins with setting up the containment structure for the day's work. The size of the containment structure depended on the scope of work (e.g., deleading, painting) and the location of the project. Next, deteriorated paint and corrosion is removed from the bridge surface and the surface cleaned with a vacuum or compressed air in preparation for applying a lead-free primer coat. Detailed descriptions of the paint removal activities observed in this study (dry blasting, wet blasting, pressure washing, power tooling, and hand tooling) are provided in the Appendix.

After the primer has dried, typically on the following day, several coats of lead-free paint are applied using either spray guns or brushes and rollers. Other supporting activities such as rigging or maintaining the blasting equipment and painting railings occur outside of the containment structure. The final stage involves the cleanup of tarps and equipment, collection of debris, and dismantling and transportation of the containment structure and scaffolding to the next work site. Completion of a full cycle of stages is necessary each day (except for painting which typically occurs on the following day) so that the newly cleaned metal does not begin to rust before painting.

Task-Based Sampling Strategy

A task-based sampling strategy was used in this study to collect personal airborne lead samples from workers. In contrast to full-shift exposure monitoring, this strategy permits the direct measurement of tasks or factors that contribute the most to workers' exposure.⁽⁸⁾ This sampling strategy is particularly useful in the construction industry because of the potential for intermittent high exposures and for designing targeted controls and selecting appropriate personal protective equipment (PPE).⁽¹⁸⁻²⁰⁾

In addition, the task-based sampling approach facilitates the evaluation of the presumed exposure levels assigned to targeted tasks by OSHA in the 1993 lead in construction standard for the purpose of selecting respiratory protection devices. Based on preliminary observations of the bridge work sites, unique tasks were defined within the various stages of the work process based on the tools used, the location of the work, and whether the worker was the operator or

assistant. The tasks defined in this manner reflect exposure generating activities and are comparable to the painting related tasks identified by OSHA as trigger tasks (Appendix). The lead in construction standard defines trigger tasks as those that require the full implementation of the standard including the provision of respiratory protection, change area, hygiene facilities, medical monitoring, etc., until exposures below the PEL are documented through monitoring of tasks.

Sample Collection and Analysis

At the beginning of each work season (May–November), contractors who had bridge painting contracts with the Massachusetts Highway Department were contacted and scheduled for field evaluation. Each work site was evaluated over a 2-week period during which sampling was performed on average 4–5 days (range 3–7) for a total of 61 work site visits. At most work sites, all workers were enrolled in the study and most workers were included in the sampling regimen.

Workers were monitored on multiple occasions performing different tasks, whereas a few workers were monitored repeatedly performing the same task because of the small size of the work crews. To ensure all tasks performed at a work site were monitored, some of the sampling was targeted to specific workers when performing the tasks of interest. The sampling strategy aimed at collecting size-separated lead aerosols due to the solubility of lead and the systemic adverse health effects of exposure, as well as the different rates of absorption from the respiratory tract.

Personal Airborne Lead Monitoring

Task-specific samples were collected from most workers for the entire duration of the task, and the samplers were replaced every time the worker performed a different task. This approach resulted in highly variable sampling times as the task durations varied within and between work sites. It was not always possible to change out samplers at the end of a task, resulting in some tasks not being sampled on a person and a few multitask samples. Task samples were collected in the inhalable size fraction using the IOM (Institute of Medicine) sampler on 25 mm diameter, 0.8 μm pore size, mixed cellulose ester (MCE) filters. Constant flow air sampling pumps (GilAir; Sensidyne Instruments, Clearwater, Fla.) were used calibrated at a flow rate of 2.0 L/min. Task samples except for abrasive blasting samples were collected from the breathing zone by placing the samplers on the workers' lapels. Abrasive blasting samples were taken from inside the blasting helmets because the IOM samples from the lapels were often destroyed by the abrasive material. A total of 18 tasks were identified, and 258 inhalable task samples with sampling duration of >15 minutes were available for statistical data analyses.

Task samples were also collected in the respirable size fraction using the cyclone sampler (BGI Inc., Waltham, Mass.) placed on workers' lapels. Respirable samples were collected on a 37 mm diameter, 0.8 μm pore size, MCE filters using the GilAir personal air sampling pumps, set at a flow rate of 2.2 L/min. A total of 39 respirable task samples (representing 8

tasks) with sampling duration of >15 min were available for statistical data analyses.

Full-shift, time-weighted average (TWA) samples ($n = 29$) were also collected in the inhalable size fraction using a second IOM sampler designated as a full-shift sampler. Due to the high frequency of overloading single filter samples, the full-shift samples consisted of consecutive, short-duration multitask samples. Of the 53 designated full-shift samples collected, only 29 samples with sampling duration of ≥ 6 hr were used in the statistical analysis. In addition, full-shift exposures were also calculated from the task-based samples ($n = 32$) when consecutive task samples with a total sampling duration ≥ 6 hr were available. Hence, a total of 61 full-shift samples comprising sampling times ≥ 6 hr were available from 10 of the 13 work sites and were used in the data analysis.

Area Airborne Lead Monitoring

Area airborne lead samples were collected from inside the containment structure and from two locations outside the containment structure (<6 meters and >6 meters) to characterize the environmental contamination from lead emissions. Three methods were used to collect airborne lead exposures including IOM samplers to collect the inhalable fraction, BGI cyclones to collect the respirable fraction, and close-faced cassettes (CFC) to collect the traditional total exposure. The CFC samples were collected on 37 mm diameter, 0.8 μm pore size, MCE filters using GilAir personal air sampling pumps set at a flow rate of 2 L/min. A total of 19 cyclone and CFC samples and 47 IOM samples were collected from inside the containment structure.

Area air samples were collected using the IOM ($n = 37$) and CFC ($n = 30$) samplers located <6 meters outside the containment; only IOM samples ($n = 35$) were collected from locations >6 meters outside the containment. Area samplers outside the containment were placed downwind from the containment structure based on the wind direction at the beginning of the shift. Wind direction was often affected by the roadway traffic; however, samplers were not moved after the beginning of the shift.

Sample Preparation, Analysis and Quality Control

All air samples were prepared and analyzed for lead according to NIOSH method 7082 for flame atomic absorption spectroscopy (FAAS).⁽²¹⁾ A field blank was collected for each type of air or surface sample media for every 10 samples or every field visit. For quality control checks during sample preparation and analysis, a lab blank and a spiked media were included with each batch of samples prepared and analyzed. The recoveries and the coefficients of variation (CV) from 60 filter and wipe media spiked at 2 ppm, and 73 filter and wipe media spiked at 20 ppm, were 102% (CV = 0.10) and 98% (CV = 0.07), respectively.

In addition, four lead dust samples from Round 5 of the Environmental Lead Proficiency Analytical Testing (ELPAT) program administered by AIHA were analyzed for lead and found to be within the acceptable performance limits defined by ELPAT for the reference laboratories.⁽²²⁾ The limit of detection

(LOD) was defined as 3 times the standard deviation of the field blanks and was estimated to be 2 μg per sample.⁽²³⁾

Characterization of Work Sites

In addition to environmental sampling, information on work site characteristics including paint removal methods, engineering controls, cleanup methods, and containment structure was gathered (using structured forms). Ten variables were used to describe the containment structure based on a guide from the Steel Structures Painting Council⁽²⁴⁾ and included information on: the containment material, air permeability of the material, support structures, treatment of joints, entryways, air makeup points, input airflow, air pressure inside containment, air movement inside containment, and exit airflow/dust collection.

Information on the cleanup methods included cleaning tarps at the end of the shift, cleaning up and collecting debris, wetting the debris before collection and use of HEPA vacuums to collect debris. From this information, two composite variables were created by combining the 4 variables describing cleanup methods and the 10 variables describing containment structure to reflect good/desirable cleanup or containment characteristics. Variables were assigned increasing scores between 1 and 10, and the composite indices were created by summing all the responses and converting the final score into percent good characteristic.

Statistical Analyses

All statistical analyses were done in PC-SAS version 9.1 and JMP version 7.0. To permit the use of data below the analytical detection limit (LOD) for statistical analyses, the LOD data were assigned a value of the LOD divided by 2.⁽²⁵⁾ The distributions of the exposure data were investigated through statistical testing using Shapiro Wilk's test and were evaluated graphically by plotting histograms and probability plots.

The data were found to be more lognormal; hence, they were log-transformed, and the geometric mean (GM) and the geometric standard deviation (GSD) were calculated. Descriptive statistics were calculated to characterize the mean and the spread of the exposure data including the minimum variance unbiased estimator (MVUE) of the arithmetic mean (AM), as this summary measure is the preferred estimator of the true arithmetic mean when the data have a lognormal distribution.^(26,27)

Pearson's correlation coefficients were obtained to evaluate the relationship between task sampling duration and the log of concentration. Frequency distributions were calculated to describe and summarize the work site characteristics observed during the site visits. The analysis of variance (ANOVA) procedure was used to conduct multiple comparisons of differences in exposures among tasks, jobs, and work site characteristics. Two-way ANOVA with or without interaction terms were used to investigate the impact of work site or locations on exposures. The GLM procedure in SAS was used with the natural logarithm of exposure as the outcome

variable, and specifying the Tukey's test option for multiple comparisons. The ANOVA F- and the partial F-statistic were used to note the overall differences between exposures, and the Tukey's test was used to identify the specific differences.

Comparisons of Air Samplers

The fraction (percent) of inhalable lead that was in the respirable size range was calculated for tasks for which paired personal IOM and cyclone samples were available. Using 34 matched personal cyclone and IOM samples from 7 tasks and 17 matched area cyclone and IOM samples from inside the containment, simple ordinary least square (OLS) regression models were developed using all data as well as separately for personal and area data. The natural logarithm of IOM concentrations was modeled as the dependent variable with the natural logarithm of cyclone concentrations as the predictor variable.

However, because both samplers have measurement error, OLS regression can provide biased estimates for the intercept (biased high) and the slope (biased low).⁽²⁸⁾ Hence, we also ran the same model using an error-in-variables model (Orthogonal regression)⁽²⁹⁾ in JMP with the assumption that the error variance was equal for the IOM and cyclone samplers. Likewise, the relationship between inhalable lead and total lead was evaluated using a set of 45 matched IOM and CFC area samples (18 from inside containment and 27 from <6 meters outside the containment) through OLS and Orthogonal regression modeling with the natural logarithm of IOM concentrations as the dependent variable and the natural logarithm of CFC concentrations as the predictor variable. Scatter plots with OLS and Orthogonal regression lines comparing the sampler types were prepared in SigmaPlot 9.01.

RESULTS

Personal Air Monitoring

Table I summarizes lead exposures and sampling duration of the bridge painting tasks monitored. Altogether, 10% (25/258) of the inhalable task samples were below the LOD, a majority being from the task of *Setup tarps*. Exposures associated with the task of *Abrasive blasting* were much higher than expected, since these samples were taken inside the blasting helmets (Type CE Abrasive Blasting Supplied Air Respirators). However, there were instances when workers would take off their blasting helmets for a short time between blasting sessions while other dust generating activities continued to occur.

In addition, when helmets were removed at the end of the shift, samples could be exposed to the settling dust, dust re-entrained from worker's clothing and helmet/hood,⁽³⁰⁾ and dust from cleanup activities such as sweeping and shoveling or taking down of tarps. Furthermore, because of the confined conditions in the containment, activities and tasks inside the containment during abrasive blasting could not be observed directly for the most part, and significant events may have been missed. Therefore, data associated with activities inside the containment should be interpreted with caution.

TABLE I. Personal Inhalable Lead Exposures of Short-Duration, Bridge Surface Preparation and Painting Tasks

Bridge Painting Tasks	Inhalable Lead ($\mu\text{g}/\text{m}^3$)						Sampling Time (min)		Time to Reach PEL (min) ^C	
	N ^A	AM ^B	Min	Max	GM	GSD	Mean	Range	No Respirator	OSHA Respirator
Power tool use	11	23,293	507	76,164	7286	5.3	291	73–402	<1	16
Hand tool use	8	3469	143	14,717	1641	3.9	271	195–340	2	16
Assist blaster	27	6346	21	34,286	858	8.2	144	27–341	1	57
Assist pressure washer	2	442	336	548	429	1.4	359	353–365	44	44
Pressure washing	2	480	232	728	411	2.2	36	16–55	33	33
Assist blaster (during no blasting)	10	363	50	1142	229	2.8	99	40–148	21	>480
Takedown tarps	30	448	7	15,750	164	4.3	85	24–242	12	>480
Clean rail	7	177	44	523	133	2.3	187	52–388	46	459
Paint without containment	14	266	9	1146	117	3.9	170	45–391	21	210
Clean surface	4	81	60	117	78	1.3	158	138–170	206	>480
Supervise	12	167	11	873	70	4.1	261	53–484	27	27
Activities <6 meters from containment	24	142	7	3832	57	4.1	189	47–486	51	51
Setup tarps	71	113	3	1158	55	3.4	102	18–248	72	>480
Abrasive blasting (inside helmet)	12	185	3	1255	45	6.3	139	20–264	19	19
Paint rail	2	47	24	70	41	2.2	140	101–179	343	343
Activities >6 meters from containment	12	59	2	239	26	4.0	129	21–508	100	100
Assist painter	6	36	5	54	23	2.9	133	49–285	446	>480
Paint in containment (spray)	4	3	1	7	3	2.1	228	105–280	>480	>480

Notes: Task samples of <15 min were excluded from data analyses.

ANOVA (natural log of lead exposure): Tasks $f = 10.4$, $p < 0.0001$; Site $f = 5.68$, $p < 0.0001$; task*site $f = 2.29$, $p < 0.0001$.

^ALOD samples: Assist painter $n = 2$, Abrasive blasting (inside helmet) $n = 2$, Activities <6 meters from containment $n = 4$.

Activities >6 meters from containment $n = 4$, Paint in containment (spray) $n = 3$, Setup tarps $n = 9$, Takedown tarps $n = 1$.

^BMinimum variance unbiased estimator (MVUE) of the arithmetic mean (AM).

^CCalculated based on the 95th percentile of task exposure corrected or uncorrected for respirator use for tasks (from Appendix).

Exposures associated with the use of hand tools, especially powered hand tools, were among the highest. These tasks were conducted very close to the workers' breathing zones, often in the overhead position, and were done without the use of shrouds or local exhaust vacuums. Other tasks not directly associated with the paint removal activities such as painting-related tasks or other activities outside the containment structure also had significant levels of lead exposures, albeit quite variable.

Results from the ANOVA models suggest that overall tasks were significantly different from one another and also differed between work sites (significant interaction term between task and work site). Overall, the task-based data suggest that high transient exposures associated with the performance of specific tasks can occur and may overexpose workers for a significant portion of the work shift.

Sampling times reflected the duration of the tasks, which depends on the nature of the work and the sequence of tasks performed by small contractors. The distributions of the sampling times of the tasks were neither normal nor lognormal with Shapiro Wilk's statistical test for normality being rejected for both log-transformed and untransformed sampling times. The summary statistics show highly variable sampling times for the individual tasks with a range of 16 min to 508 min.

An examination of the relationship of sampling time to the log of concentration revealed that, overall, there was a small but significant correlation (Pearson's correlation coefficient = 0.16, $p = 0.009$). For nine tasks, a negative correlation was observed between sampling time and the log of concentration, and was statistically significant for only one task, *Assist blaster (during no blasting)* (data not shown). A positive correlation was observed for the remaining six tasks and was significant

only for the task of *Power tool use* (data not shown). The negative correlation is most likely caused by intermittent dust-generating activities within tasks, resulting in longer periods of inactivity for longer task duration^(31,32) and, hence, the negative correlation between exposure levels and sampling time (task duration).

Table I also reports on the time a task can be performed before exceeding the PEL (8-hr TWA of 50 $\mu\text{g}/\text{m}^3$) based on the 95th percentile of the task exposure distribution. The 95th percentile concentration was also adjusted by dividing it by the assigned protection factor (APF) of the OSHA-recommended respirator for the task. Clearly, most tasks require respiratory protection for lead exposure, except for the *Paint in containment (spray)* task that requires respiratory protection for organic vapors. It is noteworthy that the use of OSHA-recommended respirators is often inadequate and results in a number of tasks exceeding 8-hr TWA of 50 $\mu\text{g}/\text{m}^3$ in less than an hour, and most exceeding the PEL in less than 8 hr.

Full-shift TWA lead exposures ranged from 2 $\mu\text{g}/\text{m}^3$ to 15,704 $\mu\text{g}/\text{m}^3$; 80% of these samples exceeded the OSHA PEL of 50 $\mu\text{g}/\text{m}^3$ on average by a factor of 30 (range: 1.3 to 314) (Table II). It is noteworthy that the overall prevalence of self-reported respirator use was 71% and ranged from 0% for the task of *Supervise* to 100% for the task of *Abrasive blasting*. Most workers reported using half-face respirators for most tasks, whereas full-face respirators and PAPRs were occasionally used. Blasting helmets were most often used by abrasive blasters.

Jobs were not significantly different from one another based on the results of the ANOVA model. In most instances, the job titles did not clearly distinguish the activities and tasks of the workers, since almost all workers performed all the tasks except abrasive blasters and spray painters, who were the only ones who did those tasks. The mean sampling time for the full-shift TWA measurements was slightly over 7 hr.

Personal respirable lead exposures for tasks paired with their corresponding personal inhalable samples are reported

in Table III. Respirable lead samples were not collected for all the tasks due to the difficulty in hanging multiple pumps on the workers. A total of 17 out of 38 (45%) respirable task samples were below the LOD, a majority being from the task of *Setup tarps*. Respirable lead levels for the monitored tasks not associated with paint removal were all below the PEL. The highest respirable lead levels were measured for the *Abrasive blasting* and *Assist blaster* tasks. Results of the ANOVA models suggest that, overall, tasks were significantly different from one another and also differed between work sites. For the task of *Abrasive blasting*, the respirable sample was collected from the lapel, whereas the inhalable sample was collected from inside the blasting helmet; hence, the respirable fraction is not calculated. The personal respirable and inhalable task samples were highly correlated (Pearson's correlation coefficient = 0.80, $p < 0.0001$). The mean respirable fraction for most tasks sampled was generally low and ranged from 11.8% to 36.3% (Table III).

The tasks of *Setup tarps* and *Activities < 6 meters from containment* had the highest fractions of respirable dust, which can be attributed to the release of fine dust remaining in the tarps after cleanup from the previous work shift. The tasks of *Assist blaster* and *Takedown tarps* had the lowest fraction of respirable dust, most likely attributed to the handling and cleanup of debris and abrasives, which consists of larger particle size material, hence, the lowest respirable fraction. The sampling times of the respirable tasks samples were similar to those for the inhalable tasks samples.

Area Air Monitoring

The results of the area samples are reported in Table IV. For the three sampler types, 23% (25/111) of the IOM samples, 17% (3/18) of the cyclone samples, and 21% (10/48) of the CFC samples were below the LOD. For samples collected inside the containment, 79% ($n = 33$) were in excess of the PEL on average by a factor of 140 (range: 1.1 to 817), whereas 31% ($n = 11$) of the samples located <6 meters outside the containment and 18% ($n = 6$) of the samples

TABLE II. Full-Shift TWA Personal Inhalable Lead Exposures During Bridge Surface Preparation and Painting

Bridge Painting Job Titles	N	Inhalable Lead ($\mu\text{g}/\text{m}^3$)							Sampling Time (min)	
		MVUE	Min	Max	GM	GSD	% > PEL	Factor ^A	Mean	SD
All Job Titles	61	1327	2	15704	246	6.5	80	30.3	437	59
Owner	1	—	21	21	21	—	0	—	484	—
Painter	3	122	44	216	100	2.2	67	3.2	386	2
Foreman	5	217	38	512	144	2.9	80	5.2	457	44
Supervisor	8	328	14	809	120	4.9	63	8.7	408	25
Blaster	2	496	22	969	147	14.3	50	19.4	416	49
Laborer	42	2184	2	15704	349	7.2	88	37.7	444	65

Notes: TWA samples of <6 hr were excluded from data analyses.

ANOVA (natural log of lead exposure) for Jobs, f -statistics = 1.15, p = Not significant.

^AAverage exceedance factor for job titles.

TABLE III. Personal Respirable Lead Exposures of Short-Duration Bridge Surface Preparation, and Painting Tasks

Bridge Painting Tasks	N ^A	Respirable Lead ($\mu\text{g}/\text{m}^3$)					Sampling Time (min)		Respirable Fraction	
		AM ^B	Min	Max	GM	GSD	Mean	SD	Percent (%)	SD
Abrasive blasting	4	22,374	140	36,364	3,331	14.2	160	120	—	—
Assist blaster	5	1876	109	8312	730	5.2	40	11	15.4	9.2
Assist blaster (during no blasting)	1		34	34	34		135		24.5	
Takedown tarps	2	29	3	55	12	8.2	142	17	11.8	15.5
Activities <6 meters from containment	5	10	2	29	7	3.0	218	159	36.3	36.2
Setup tarps	16	10	2	32	6	2.8	121	63	30.4	49.5
Supervise	2	8	3	13	6	2.7	230	158	15.5	7.7
Activities >6 meters from containment	3	5	2	8	4	2.1	158	101	17.1	13.0

Notes: Task samples <15 min were excluded from data analysis. Reporting only data where cyclone samples were matched with the IOM samples. ANOVA (natural log of lead exposures) for Tasks: $f = 29.31$, $p < 0.0001$; task*site: $f = 3.97$, $p = 0.0042$ (site was not significant).

^ALOD samples: Activities <6 meters from containment $n = 3$, Activities >6 meters from containment $n = 2$, Setup tarps $n = 10$, Supervise $n = 1$, Takedown tarps $n = 1$.

^BMinimum variance unbiased estimator (MVUE) of the arithmetic mean (AM).

located >6 meters outside the containment exceeded the PEL. For a subset of $n = 29$ matched IOM area samples data collected from the three locations (inside containment, outside <6 meters, and >6 meters from the containment) on the same day, the ANOVA models suggest that overall the mean of the log concentrations and, therefore, the GMs of the different locations were significantly different from one other and also differed between work sites. Tukey's multiple comparisons suggest that the GMs of samples located <6 meters ($\text{GM} = 24 \mu\text{g}/\text{m}^3$) and >6 meters ($\text{GM} = 9 \mu\text{g}/\text{m}^3$) outside the containment were not significantly different from one another

but were both significantly different from the GM of the samples collected inside the containment ($\text{GM} = 503 \mu\text{g}/\text{m}^3$).

Sampler Comparisons

The OLS and orthogonal regression models for relationships between the IOM (inhalable) sampler and the respirable cyclone or the traditional CFC sampler are plotted as Figure 1. For the comparison of IOM to cyclone, the OLS regression model based on area samples is different from that based on personal samples, in part due to a few outlier samples for which the respirable sampler measured higher concentration than the

TABLE IV. Area Inhalable and Respirable Lead Exposures During Bridge Painting

Area Location	N ^A	Lead Exposures ($\mu\text{g}/\text{m}^3$)					Sampling Time (min)	
		AM ^B	Min	Max	GM	GSD	Mean	SD
IOM								
Inside containment	42	23,362	<2	40,866	500	19	201	143
Outside containment (<6 meters)	35	64	<2	471	16	6	323	121
Outside containment (>6 meters)	34	23	<2	121	9	4	322	123
Closed Face Cassette								
Inside containment	18	15,311	13	26,944	1430	11	242	138
Outside containment (<6 meters)	30	26	<2	439	10	4	292	131
Respirable Cyclone								
Inside containment	18	4553	<2	11355	123	20	106	95

Notes: For the ANOVA analyses, only location and date matched samples were used. ANOVA (natural log of lead exposure) for Location, $f = 56.63$, $p < 0.0001$; Site: $f = 6.47$, $p < 0.0001$.

^ALOD samples: IOM Inside containment $n = 6$, IOM outside containment (<6 meters) $n = 9$, IOM outside containment (>6 meters) $n = 10$, CFC outside containment (<6 meters) $n = 10$, Cyclone inside containment $n = 3$.

^BMinimum variance unbiased estimator (MVUE) of the arithmetic mean (AM).

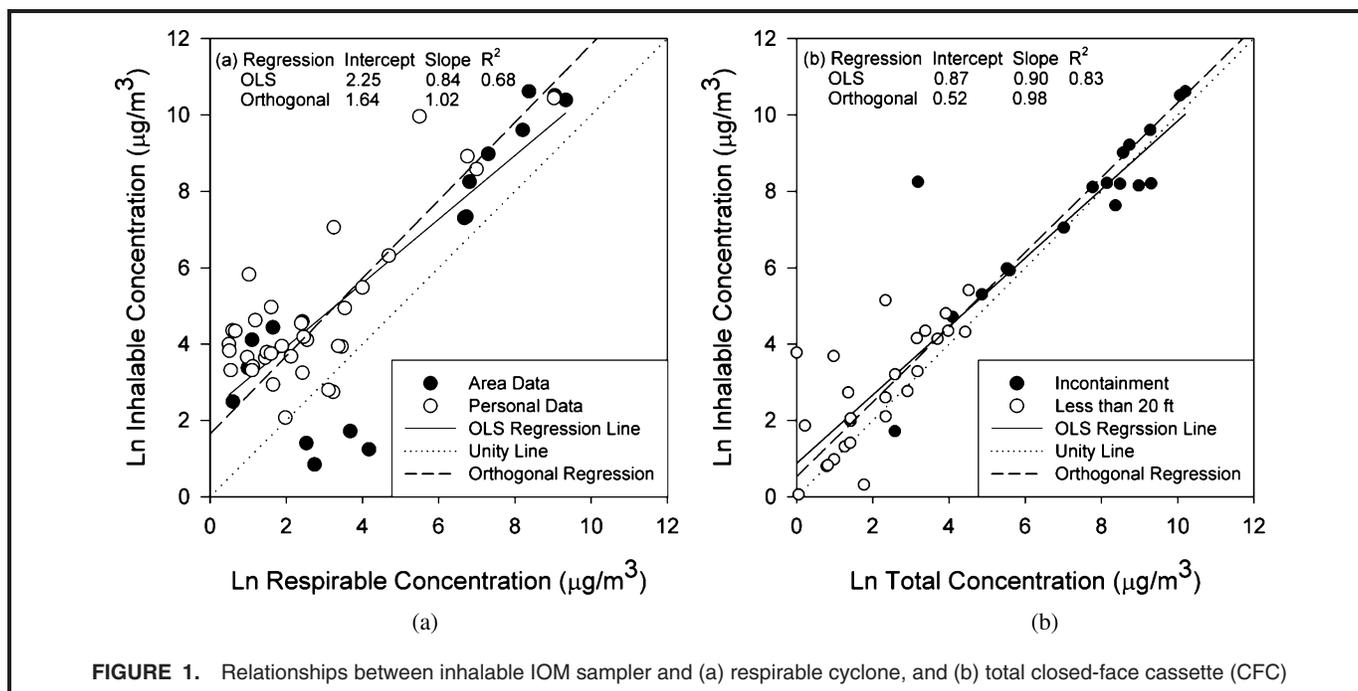


FIGURE 1. Relationships between inhalable IOM sampler and (a) respirable cyclone, and (b) total closed-face cassette (CFC)

inhalable sampler (Figure 1a). The OLS regression model gave a large and significant intercept and a smaller slope (0.84) albeit not significantly different from 1. As expected, the orthogonal regression gave a slope of 1.02 and a smaller intercept of 1.64. Both models gave intercepts larger than 0, likely due to the collection of larger particles by the IOM sampler.

Ratio of the IOM/cyclone (median = 5.63) suggests that the inhalable fraction is substantially greater than the respirable fraction. Although moderately large R^2 is observed for this association, there is a large amount of scattering of data points above and below the regression line. This may be due to differences in particle size distribution of lead for tasks and locations, therefore displaying large variability in the ratio of inhalable to respirable lead exposure.

For the relationship between the IOM and the CFC samplers, Figure 1b shows that most data points are fairly close to but above the unity line, suggesting the CFC sampler slightly underestimates the IOM sampler in these data. This is also shown by the median ratio of the IOM/CFC samplers (1.40). The relationship between the IOM and the CFC changed a little after stratifying the OLS regression by the two location types, likely due to the difference in particle size distribution between the two locations. As expected, the slope from the orthogonal regression is larger than that from OLS regression, whereas the intercept is smaller. Both models gave slopes not significantly different from 1 and intercepts larger than 0, indicating that the IOM consistently collects more of the larger particles.

Work Site Characteristics

Detailed information on work site characteristics obtained from the sampling forms and observations are reported in Table V. The denominators in Table V are variable due to

some work site assessments not being applicable. For example, abrasive blasting was not carried out by all contractors, or the containment structure was present during only 47 of the 61 work site visits. At most work sites, several paint removal techniques such as abrasive blasting, hand and power tool use, and pressure washing would be performed simultaneously or would be performed within a work day. We assigned the main paint removal method to a work day based on the industrial hygienist's judgment of the dominant paint removal activity that was noted on sample collection forms.

Abrasive blasting was the dominant work site activity in 32 out of 60 work site assessments, followed by painting, hand and power tool use, pressure washing, and setting up equipment and tarps. Whenever abrasive blasting was done, both steel shot and coal slag abrasives were used equally. On most work site visits, the tarps were cleaned at the end of the shift (82%), as was the cleanup and removal of debris after paint removal activities (56%).

Mechanical ventilation of the containment area was observed only in 26% of the work site visits and only during dry abrasive blasting; dust collection (filtration) was present in 7% of the work site visits. The mean cleanup index score (good cleanup methods) was $48 \pm 19\%$ (range: 18–100%) suggesting opportunities for significant improvement in the way cleanup was carried out every day, such as increased use of HEPA vacuums, wet methods, and enclosed or shrouded systems that do not generate debris. Similarly, the mean containment index score (desirable containment structure characteristic) was $57 \pm 11\%$ (range: 44–84%), again suggesting opportunity for improving the containment ventilation system to reduce fugitive emission.

The results of the full-shift inhalable lead exposures stratified by work site activity for the three locations (in

TABLE V. Work Site Characteristics of Small Contractors During Bridge Surface Preparation Painting Projects

Site Characteristics	Percent % (n/N)
Work Activities (one variable)	
Abrasive blasting	53 (32/60)
Hand and power tools use	10 (6/60)
Pressure washing	10 (6/60)
Setup	5 (3/60)
Painting	22 (13/60)
Type of Abrasive (one variable)	
Coal slag	53 (17/32)
Steel shots/bar	47 (15/32)
Site Cleanliness Factors	
Clean tarps (Yes/No)	82 (50/61)
Clean debris (Yes/No)	56 (34/61)
Wet debris before cleaning	24 (14/57)
HEPA vacuum use	50 (25/50)
Controls and Containment	
Ventilation	26% (12/47)
Air impermeable containment	64% (30/47)
Exhaust air filtration	15% (7/47)
Controlled makeup air	4% (2/47)
Forced input air	21% (10/47)
Rigid support structure	23% (11/47)
Fully sealed joints	17% (8/47)

Note: N = number of site-visit days (multiple observation days per work site).

containment, outside <6 meters, and >6 meters) are displayed in Figure 2. Highest GM exposures were measured inside the containment during dry blasting, followed by wet blasting and power tool use, but their difference were not statistically significant.

However, these GM exposure levels were significantly higher than those for nonpowered hand tool use, pressure washing, and painting. For the activity of hand tool use, GM exposure levels outside the containment were higher than inside the containment albeit not statistically significant. The containment structure during this activity was often only partially enclosed. In addition, painting activity was often accompanied by hand tool use or movement of the tarps, resulting in higher than expected GM exposures for this activity.

We also evaluated the effect of cleanup methods and containment structure on inhalable lead exposures for the three locations. The GM exposure levels were not significantly different by the various containment related variables nor by the cleanup methods. Contrary to expectation, presence of ventilation and the use of HEPA vacs were associated with higher GM exposure levels, in part because these devices were used during activities that produced the highest exposures. The GM levels of inhalable exposures at >6 meters from the

containment were significantly lower for work site days with higher scores for the cleanup index than work site days with lower scores, approached the level of significance for locations <6 meters from the containment, but did not differ significantly for locations inside containment. As expected, the GM levels of inhalable exposures inside the containment were significantly higher for work site days with higher scores for the containment index than work site days with lower scores. However, the GM exposure levels were not significantly different between high ($\geq 50\%$) and low (<50%) containment index scores at locations outside the containment.

DISCUSSION

The lead exposure data reported in this study were collected one year after the implementation of the lead in construction standard, yet evidence from the 2005 OSHA review of the standard suggests elevated lead exposures and blood lead levels continue to be a concern for construction painters and deleaders.⁽¹²⁾ The review also reported high occurrence of noncompliance with the lead standard among painting contractors, especially among small painting firms employing fewer than 10 workers, who received 68% of the violations cited in 2003. The subsections of the standard that were most frequently cited for violations over the period of 1993–2003 were related to failures in: conducting initial assessment and related violations (34%), hygiene facilities and practices (11%), medical surveillance (10%), and respiratory protection (9%).

Furthermore, the review reported that newer technologies such as shrouded power tools, vacuum blasting, wet blasting, chemical stripping or remotely operated devices are not widely used; however, many of these technologies were already available at the time of this study. Paint removal and surface preparation technologies and their application, therefore, have likely not changed much over this period.

Few studies have focused on detailed investigation of these small-size contractors in an industrial sector that is difficult to study and poses numerous challenges to exposure assessment, control evaluation, and implementation. These data provide comprehensive information on the tasks and exposures associated with bridge surface preparation and painting among small contractors. They can be used to augment the OSHA trigger tasks that lack quantitative exposure data and can be used to guide initial assessments and the requirements for worker protection and monitoring while site-specific exposure assessments are being conducted.^(4,12) Given that small contractors are often the least evaluated work sites, these data are extremely valuable in understanding their exposures and in planning intervention and training activities, as well as the selection of appropriate respiratory protection, administrative, and engineering controls.

Caution must be exercised in comparing these task data with other task data described by OSHA or other researchers that may represent exposure measurements of different durations (e.g., full shift).

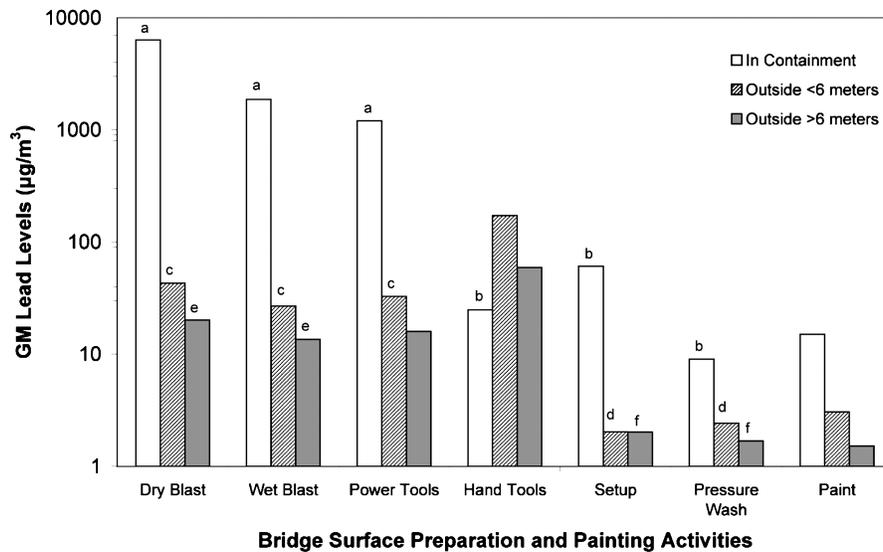


FIGURE 2. Area lead exposure levels for bridge surface preparation and painting. Bars with the same letter are not significantly different from one another.

The issues associated with trying to compare the short-duration task exposure data with the OSHA-specified task levels are well described by Goldberg et al.⁽⁸⁾ In their study, they compared short-term task samples with shift-long tasks defined by OSHA by assigning zero exposure to the remainder of the time not accounted by the task. The differences in the task-based, full-shift exposures still persisted although they were not as clear as the short-duration differences in exposure. Among small-sized contractors, the scope of work requires rotation of tasks within a day so that tasks are of shorter duration than 8 hr or full shift. Therefore, assuming zero exposure for the remainder of the work shift will vastly underestimate worker exposures.

Part of our ongoing work is to develop estimates of full-shift exposures based on the task exposure levels and worker diaries of time at task and to evaluate the impact of task exposure level and duration on the full-shift exposure. This approach will allow more realistic estimation of the full-shift exposure and the examination of the PPE selecting strategy using either the task estimates or the full-shift estimates of exposure.

Task-Based Exposures

The task-based data demonstrate that extremely high levels of exposure to inhalable lead can occur in a range of tasks, including some tasks not listed by OSHA as requiring respirators (such as *Activities outside containment, Pressure washing, Paint railing, or Supervise*). These data represent some of the highest lead exposures reported in the literature for surface preparation tasks. Although these data are of short-duration tasks, the levels are very high and are cause for serious concern. Furthermore, the data suggest that nearly all tasks, including tasks conducted outside the containment structure, can yield exposure levels above the PEL. The tasks associated with brush and roller painting occurred most frequently simulta-

neously with other surface preparation tasks within the same containment. Spray painting was often conducted separately from other surface preparation tasks but occasionally with movement of the tarps. Thus, these data suggest that the OSHA-required respiratory protection is often inadequate, and that all tasks require at least a half facepiece respirator whenever surface preparation occurs, including tasks or activities conducted outside the containment. Because workers at these sites perform several tasks within a work shift, they will likely need multiple types of respirators; therefore, a practical strategy for respirator selection to ensure that the 8-hr TWA exposure does not exceed the PEL should take into consideration multiple factors, including: the type of lead removal method, the type of containment structure and control measures, the amount of time expected for the tasks, the contribution of task time, and task level to the full-shift measurement.

The exposure levels used by OSHA for the various comparable tasks are also reported in the Appendix. Comparing these values with the measured data shows that the GM or the maximum exposure for a number of tasks exceeded the upper range of the OSHA presumed exposure levels for similar tasks (such as *Assist blaster, Painting without containment, Hand and power tools use*). Similar results have been reported by Scholz et al.⁽⁶⁾ for the task of dry sanding, so for workers performing these tasks the OSHA-specified respirators would not adequately protect them if the tasks were sustained for a full shift. However, it is not entirely appropriate to compare the short-term task exposures with the shift-long criteria described by OSHA. It is likely that for small projects such as the ones under study, a variety of “typical day” daily exposures need to be generated that represent the various combinations of tasks and their duration that can exist. Moreover, the job title does not adequately differentiate the activities and exposures of workers, since most workers regardless of their job title are

involved in most of the tasks. Therefore, identifying typical day activities and exposures may be the most practical option for selecting respiratory protection.

The data on task exposure levels show that some tasks were highly variable with GSDs in the range of 1.4–8.2, identifying the need to explain the large variation in task exposures. This underscores the need to collect auxiliary information on factors that may affect task exposures. The ANOVA models identified work site to be an important factor affecting task exposure levels. Work site encompasses a large number of exposure determinants, such as differences in paint removal methods, control measures, scope of bridge rehabilitation work, and manner in which workers performed their tasks.

Lead content of the paint removed from the bridge surface is likely a significant factor impacting on exposure levels; however, this information could not be obtained during this study. To do so would require at least daily and often multiple bridge-surface paint chip samples to be collected and matched with task samples over the day because the lead content across sections of the bridge is not constant. This is because during previous repainting, old paint was probably removed to the bare metal in some sections (especially at the abutments), whereas in other sections, only the surface paint and rust was removed before repainting. Identifying the determinants of task exposures could reduce the variability in task levels, permitting improved decision making on selection of respirators and control measures.

Sampler Selection

Present results suggest that particle size distribution is different for the different tasks. Although some tasks such as *Assist blaster* had high inhalable lead exposures, only a small fraction of it is in the respirable size range. Other tasks such as *Activities <6 meters from the containment* had relatively lower inhalable exposures but a larger fraction of that exposure is in the respirable size. The limited results suggest the majority (64–89%) of the lead exposure associated with surface preparation tasks was in the nonrespirable particle size range. Previous studies have reported the importance of particle size distribution on the absorbed dose of lead;^(33–35) thus, a complete characterization of the tasks and their particle size distribution is necessary for epidemiologic studies requiring estimates of absorbed dose.

Many studies are now using the IOM samplers as new occupational exposure limits (OELs) are based on the inhalable criteria as opposed to the traditional “total” exposure; thus, numerous studies have compared the field performance of the IOM with the CFC sampler for a number of exposure agents and work settings.^(36–41) Most of these studies have reported underestimation of exposure by the CFC sampler by a range of factors depending on the exposure scenario based on OLS regression analysis or a simple ratio of the two samplers.

A recent study comparing the total with inhalable sampler suggests that the CFC may provide equivalent results to the IOM samplers if the inner wall losses in the CFC are taken into consideration.⁽⁴²⁾ In the present study, both the OLS and

orthogonal regression were used to demonstrate the potential bias in the estimates of the slope and intercept using OLS regression when both x and y variables are measured with error. Although this modeling technique is frequently used in the clinical sciences field, it is rarely used in the field of industrial hygiene.⁽⁴³⁾ These and other studies comparing two measurement methods with the objective of creating calibration curves will likely benefit from using the more appropriate error-in-variables models that are now becoming available in standard statistical packages.

Environmental Contamination

Area full-shift TWA exposure samples collected from outside the containment structure show significant emission of lead to the environment surrounding the work sites, which is consistent with previous reports that suggest containment structures such as tarpaulins only achieve 40–70% containment.⁽⁴⁴⁾ With such high exposures inside the containment, the 30–60% emission from the containment can result in significant contamination of the areas surrounding the work site. A single 8-hr TWA area exposure $>405 \mu\text{g}/\text{m}^3$ will exceed the U.S. Environmental Protection Agency’s (EPA) quarterly ambient exposure limit of $1.5 \mu\text{g}/\text{m}^3$.⁽¹²⁾

However, this standard is intended for permanent structure (e.g., smelters) and is rarely enforced for mobile work sites such as bridge work sites.⁽⁴⁴⁾ The results of the area exposures can be used to inform the extent of lead emissions from these containment structures, as well as possible redistribution by the roadway traffic or runoff rainwater. Based on the mean containment index score of 57% (range: 44 to 83%), our data suggest that there is significant room for improvement of these structures to minimize lead emissions to the environment. This will invariably result in higher exposures inside the containment, requiring a more integrated approach between EPA and OSHA to ensure both worker and environmental protection.⁽¹²⁾

Assessment of the work sites shows that ventilation was present during only 12 (26%) work site visits over the 2 years. Future intervention studies can thus focus on understanding the impediments to the use of existing engineering control technologies, such as ventilation or vacuum blasting, and possibly the development of more appropriate technologies that are affordable and can be implemented with ease by small contractors

CONCLUSION

This study clearly demonstrated that uncontrolled lead exposure can occur during bridge surface preparation and painting and may present a serious hazard not only to the workers but also to the environment in the vicinity of the work sites. Task-based exposures are extremely useful in identifying high-exposure activities and offers opportunities to target tasks for appropriate PPE, engineering controls, or training. Task exposures, however, were highly variable and require additional information on exposure determinants to improve their utility.

Limited data from this study and others have shown that differences between tasks are diluted when evaluating full-shift TWA exposures, making intervention difficult and less targeted. The study also found very infrequent presence of engineering controls, such as the use of vacuums or shrouds on blasting equipment or on powered hand tools. Worker exposure can be significantly reduced by instituting engineering controls first, followed by the use of respiratory protection. Fugitive emission to the environment can also be reduced by instituting engineering controls and improving the containment structure.

We found work practices and patterns to vary significantly among small contractors, which results in variable frequency of tasks, duration of exposures, and exposure concentrations. Therefore, task patterns and exposure and time profiles for tasks need to be well characterized. We also measured high levels of surface contamination and worker skin exposure to lead and observed a significant potential for family exposure by means of take-home lead exposure, which we address in a companion article in this issue.⁽¹⁷⁾

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APPENDIX—DESCRIPTIONS OF TASKS SAMPLED

Abrasive blasting (OSHA list 3: >2500 $\mu\text{g}/\text{m}^3$). This is the most common technique used for removing paint from bridge surface. A high-velocity stream of abrasives is delivered to the surface using either compressed air or water. The abrasives could be metallic, such as steel grit or steel shots, or nonmetallic such as coal slag (black beauty). As the paint

is removed, small particles of the abrasive and paint become airborne.

Assist blast during blasting (OSHA list 2: 500–2500 $\mu\text{g}/\text{m}^3$). While abrasive blasting is being performed, other workers perform support activities such as pot tending, operating equipment, moving hoses, and shoveling and collecting waste. Their exposure results from dispersion of lead dust due to blasting, as well as from their activities that require them to handle and disturb lead-contaminated surfaces.

Assist blast during no blasting (OSHA list 2: 500–2500 $\mu\text{g}/\text{m}^3$). Activities in this task are similar to the activities in takedown tarps, except there is no handling of tarps. This task occurs when blasting is interrupted for whatever reason.

Assist painting (OSHA list 1: 10–500 $\mu\text{g}/\text{m}^3$). Assist the painter by mixing paint, moving hoses and tarps, and tending equipment for spray painting.

Assist pressure washing (OSHA list unspecified). Assist the pressure washer by moving hoses and tarps and tending equipment for pressure washing.

Clean railings (OSHA list 1: 10–500 $\mu\text{g}/\text{m}^3$). Manually operate scrapers and sanders used to remove loose paint and rust from the surface of bridge railings. This activity was performed away from the containment where the major deleading activities were performed.

Clean surface (OSHA list 1: 10–500 $\mu\text{g}/\text{m}^3$). Clean bridge surface by sweeping or washing to prepare for painting or deleading.

Hand tool cleaning (OSHA list 1: 10–500 $\mu\text{g}/\text{m}^3$). Manually operate scrapers and sanders used to remove loose paint and rust from the surface. This is by far the slowest and most labor-intensive process and is hardly used as the main method of paint removal. Mostly used to remove loose material while intact rust, paint, and scales remain.

Activities greater than 6 meters from containment (OSHA list unspecified). This includes workers not directly involved in exposure-generating activities but includes those who are exposed due to their activities or the activities of their co-workers. This generally includes rigging scaffolding, repairing equipment, office work, transporting equipment and supplies, and other miscellaneous activities.

Activities less than 6 meters from containment (OSHA list unspecified). This includes workers not directly involved in exposure-generating activities but includes those exposed due to their activities or the activities of their co-workers. This generally includes rigging scaffolding, repairing equipment, and other miscellaneous activities.

Paint in containment (OSHA list 1: 10–500 $\mu\text{g}/\text{m}^3$). Painting the bridge surface using mainly spray paint, inside a fully contained structure. When this task was performed, there was relatively little paint removal activity.

Paint railings (OSHA list unspecified). Painting bridge railings using brushes and rollers. A low exposure task

performed away from the containment where the major deleading activities were performed.

Paint without containment (OSHA list 1: 10–500 $\mu\text{g}/\text{m}^3$). Painting the bridge surface using brush, rollers, or spray paint, without containment or in partially contained structure. Spot painting was done using rollers and in conjunction with hand tool or power tool use, resulting in higher exposures than would be expected for painting.

Power tool cleaning without dust collection (OSHA list 2: 500–2500 $\mu\text{g}/\text{m}^3$). This method mechanically removes corrosion and paint from the surface using powered tools. Whenever this method was encountered, it was always used without a dust collection system, which was believed to be cumbersome. This method is labor intensive, results in low productivity, and is best used for hard to reach areas. When power tools are used to clean to bare metal (as was mainly encountered in this study), the amount of dust generated is typically high and concentrated close to the user.

Setup tarps (OSHA list 2: 500–2500 $\mu\text{g}/\text{m}^3$). This task involves handling and moving tarps during setting up of the containment structure. Exposure levels are variable depending

on what the tarps were used for previously and methods of cleaning tarps at the end of the day.

Supervise (OSHA list unspecified). This task lasted throughout the work shift and was assigned mainly to those in charge of the work, such as company owners, managers, and foreman. They performed many tasks for very short duration for demonstration purposes or to assist workers. They were in and out of containment inspecting the quality of work being performed.

Takedown tarps (OSHA list 2: 500–2500 $\mu\text{g}/\text{m}^3$). This task involves handling and moving tarps during takedown of the containment structure while other ancillary activities such as washing, sweeping and shoveling, waste disposal, etc., are being conducted. Exposure levels are high and variable depending on lead removal activities for the day and methods of cleaning tarps.

Water jetting or pressure washing (OSHA list unspecified). High-pressure water is used to dislodge paint and corrosion from the surface. Even at high pressure, this method is slow and cannot remove tight rust. Pressure washing is commonly used after abrasive blasting to remove abrasive and debris stuck to the surface.