

A Task-Based Approach to Assessing Lead Exposure Among Iron Workers Engaged in Bridge Rehabilitation

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The assessment of worker exposures to airborne contaminants in the dynamic environment present at most construction sites poses considerable challenges to the industrial hygienist. In this study, we applied a task-based approach to the assessment of lead exposure among structural steel iron workers engaged in a large, complex bridge rehabilitation project. We evaluated the usefulness of task-based exposure data for the development of worker protection programs. Task-specific and multitask samples were collected, and operation-specific and 8-hr time-weighted averages were calculated. The task-specific data showed significant differences in exposure levels among different tasks. Arithmetic mean exposures varied from 1,357 $\mu\text{g}/\text{m}^3$ lead for torch cutting and 989 $\mu\text{g}/\text{m}^3$ for scaling to 31 $\mu\text{g}/\text{m}^3$ for reaming and 4 $\mu\text{g}/\text{m}^3$ for drilling. Our task-specific data were compared with the task-based exposure levels presented by OSHA in its Lead Exposure in Construction—Interim Final Rule (29 CFR 1926). There was good general agreement between our results and OSHA's reported data. Task-based data were very useful in exposure assessment and much more precise than full-shift and operation-based measurements in guiding strategies for worker protection. These findings suggest that task-based data should routinely be collected in evaluating exposure to lead and perhaps other toxic substances in construction work. Am. J. Ind. Med. 31:310-318, 1997. © 1997 Wiley-Liss, Inc.

KEY WORDS: lead exposure; task-based assessment; construction industry; OSHA lead standard

INTRODUCTION

A growing number of construction workers are finding employment in the rehabilitation and repair of the nation's decaying transportation infrastructure. A dramatic increase has occurred in recent years in such rehabilitation work,

particularly following Congressional enactment, in 1991, of the Intermodal Surface Transportation Efficiency Act (ISTEA), which provided vital federal support for this often long overdue work. Within the infrastructure repair sector, expanding resources are being devoted to bridge rehabilitation. Since most bridges are coated with lead-based paint, an increasing number of workers are at risk of occupational exposure to lead. It is estimated that more than 57,000 construction workers engaged in structural steel rehabilitation and repainting are now potentially exposed to lead in this country [NIOSH, 1992; OSHA, 1993].

In construction (as in other industries), quantitative evaluation of the magnitude of exposures to chemical and physical agents is integral to developing programs designed to protect workers. However, by and large, scant attention and resources have been devoted to such assessment for the

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construction industry [Ringen et al., 1995]. To be sure, exposure assessment in this setting presents difficulties generally not found in fixed industry. In construction, the conditions determining the magnitude of worker exposures are extremely variable and dynamic. Construction projects can differ enormously in scope and duration; they can last several hours or several years. They can involve several workers from one trade performing one task or hundreds of workers from many trades performing numerous tasks. Work and environmental conditions at construction sites vary from sector to sector (e.g., new construction, highway, demolition), and from project to project within the same sector. Conditions also vary over time at the same project, sometimes over very short periods of time. A worker can start the day working in an open space and end the day in an enclosed room.

A newly developed “task-based” approach to exposure assessment appears to hold promise as a method that can take into account the variability in exposure that exists in the construction industry [Susi and Schneider, 1993; Greenspan et al., 1995; Susi and Schneider, 1995]. The starting point of this approach is the recognition that only through a more sophisticated and comprehensive understanding of tasks—their nature and the conditions causing and exacerbating exposures—can controls be realistically designed to reduce exposure. A traditional industrial hygiene approach, which focuses on capturing an 8-hr time-weighted average (TWA) exposure, independent of a worker’s task, might mask significant excursions associated with the performance of particular tasks, and could miss opportunities to control such excursions. By contrast, a task-based approach disaggregates these average exposures and times and can facilitate separate and specific evaluation of exposure determinants, such as materials and environmental conditions. If significant exposure determinants can be identified, engineering controls and other worker protection strategies can be focused on those particular conditions that generate the highest exposures.

In this study, we used a task-based approach to exposure assessment to examine whether measurable differences exist among various lead-disturbing tasks, in the context of a complex, large-scale, multiyear bridge rehabilitation project. The results of exposure assessment at this project were then compared to task-based levels introduced in OSHA’s Lead Exposure in Construction—Interim Final Rule (29 CFR 1926). Additionally, we sought to determine whether assessment of these differences in exposure could assist the industrial hygienist in developing strategies, including engineering and work practice controls, to protect workers. This is the first study to present and analyze task-based exposure assessment results for lead levels measured in bridge rehabilitation.

BACKGROUND

The demolition, rehabilitation, and repair of steel structures involve two distinct kinds of activities. Both disturb lead-based paint: (1) the removal of the existing coating in preparation for repainting; and (2) the rehabilitation and/or demolition of the existing steel and concrete which includes removing old steel, replacing it with new steel and reinforcing existing structural elements [Goldberg et al., 1995]. The study described here involves exposure assessment during the second activity, specifically the rehabilitation of a steel bridge, constructed in 1908, which is 6,087 feet from end to end, has two 1,600-foot-long approaches entirely over land and three suspended spans that rise 130 feet above water. The bridge has two levels: an upper level supporting roadways and outer walkways, and a lower one containing railway tracks and roadways. The rehabilitation entailed the reconstruction of large sections of the bridge, including walkways, roadways, and support structures such as trusses, hangers, beams, and plates.

The rehabilitation was performed largely by ironworkers using pneumatic tools. Two methods were employed to remove steel beams: they were either “cut” with an oxyacetylene torch, or the rivets connecting beams to each other or to other structural parts were mechanically removed with a pneumatically driven hammer or “rivetbuster”. Before new steel beams could be installed to replace those removed, the surfaces of the steel already in place had to be cleaned of any coating or corrosion at the point of connection. This was accomplished by pneumatic finger scalers and grinders. Once the steel was cleaned, the new beams were connected with bolts tightened with a pneumatic air gun (“bolting up”). If holes had to be made, this was accomplished with an electric drill. Existing holes not large enough for the bolts were enlarged with a pneumatic reamer. In addition to performing these tasks, iron workers cleaned the work site, and moved and lifted steel and supplies.

During our investigation, most of the iron work took place at five main locations on the bridge. There were three identical under-bridge platforms, suspended from steel rails, constructed solely for the project. Located at either end of the bridge and in the center, the platforms were moved stepwise across the structure as the work at one location was completed. The other main work locations were at the two anchorages where massive steel reinforcement plates or frames were added to strengthen the bridge. Typically, crews on the platforms consisted of 15–20 workers; crews of 8–10 worked at the anchorages. With only minor variations, the tasks described above were performed repetitively during the period in which exposure assessment was performed.

Before May 1993, when the OSHA Lead in Construction Standard was promulgated, construction workers performing such work were afforded only minimal regulatory protection. The new standard extended to lead-exposed

construction workers the basic protection afforded industrial workers by the general industry standard, promulgated in 1978 [OSHA, 1978; OSHA, 1993]. The provisions of the construction standard are generally the same as those of the general industry standard. However, several requirements of the former are tailored to such features of the construction environment as the short duration of many jobs, the varying physical environment from job to job, and the transient nature of the workforce. In order to provide proper worker protection, especially respirators, in the period between job onset and the completion of exposure assessment—which can take weeks—the construction standard introduces “presumed task-based exposure levels”. Hence, in the absence of exposure assessment results, the extent of worker protection is related to the task performed by a worker.

METHODS

Personal Monitoring

Personal monitoring of iron workers was performed periodically over the course of the project. Workers were chosen for monitoring based primarily upon work location—most often a reasonably accessible underbridge platform—and tasks to be performed. Sampling was conducted with a closed faced cassette containing a 37-mm mixed cellulose ester filter of 0.8- μ m nominal pore size at flow rates of approximately 2 L/min. Sample analysis was performed according to NIOSH method 7400 by a laboratory accredited by the American Industrial Hygiene Association. In addition to air samples, bulk samples of paint chips were collected from various areas of the bridge in order to establish the presence of lead-based paint, and the percent of lead by weight in the paint. Since there is no accepted protocol for bulk sampling of paints from steel structures, samples were taken either by cutting an approximate two inch square area with a knife and removing as much of the paint as possible down to bare steel, or by simply tearing off a piece of peeling paint that left no residue on the underlying steel surface.

To the extent possible, the approach to worker monitoring was to collect task-specific samples by replacing the filter cassette every time that the worker changed his task. For each of these samples, the duration of the task was noted. Because of practical considerations, it was not always possible to gather unique samples for each task. Foremost among these were frequent unpredictable changes from one task to another and the fact that workers sometimes performed their tasks in areas that were not readily accessible for monitoring (e.g., one-man moving platforms). Samples gathered during the performance of more than one task were labeled “multitask” samples. Although both the tasks performed and the total time worked during the collection of such a sample were noted,

TABLE I. Tasks and Operations in Bridge Rehabilitation Work, NYC 1993–1994

Operation	Task
Removing (old steel and paint)	Torch cutting
	Rivet busting
	Scaling
	Grinding
Installing (new steel)	Drilling
	Reaming
	Bolting up
Cleaning	Cleaning
Other (supervising, lifting, hauling)	

the duration of each task comprising the sample was not known. Full shift data were gathered by collecting consecutive task-specific and/or multitask samples from the same workers throughout the shift.

The work was divided into broader categories, or “operations,” each of which entailed the performance of a number of tasks, designed to accomplish a particular end. Thus, the tasks of torch cutting, rivetbusting, scaling and grinding were grouped in the operation “removal” (of steel and coating), while the tasks of reaming, drilling and bolting up were grouped in the operation “installing.” In addition, iron workers would occasionally clean the work area, which entailed manual lifting of gross debris and sweeping/shoveling of finer debris. Cleaning up is noted both as a task and an operation. Iron workers performing tasks that are not associated with the generation of dust, were also monitored. Such tasks, which included lifting steel, supervising, and transporting supplies, were placed in the “other” category. Table I lists the tasks and operations.

Comparison With OSHA Data

Data presented and discussed in the preamble to the Lead Exposure in Construction Standard were compared to task-specific data from the present study. Since OSHA prescribes worker protection based on the 95% upper confidence limit (UCL) of the arithmetic mean exposure, these values were calculated for our data and compared to OSHA’s values. In addition, since OSHA data are presented as 8-hr TWAs, this value was calculated for a subset of our data, by assuming zero exposure for the period not monitored.

Statistical Analysis

Descriptive statistics were calculated to characterize the distribution of airborne lead concentrations for various subsets of the samples, in particular by task and operation.

TABLE II. Task-Specific Airborne Lead Level and Mean Sampling Period at a Bridge Rehabilitation Project, NYC 1993–1994*

Tool	n	AM ($\mu\text{g}/\text{m}^3$)	SD	Range ($\mu\text{g}/\text{m}^3$)	GM ($\mu\text{g}/\text{m}^3$)	GSD	MT (min)
Torch cutting	25	1,357	1,248	63–5,134	843	3.1	132
Scaling	11	989	774	168–2,743	722	2.4	75
Grinding	19	503	1,221	28–5,509	202	3.2	121
Rivet busting	27	245	295	10–1,200	136	3.2	157
Bolting up	11	57	82	7–286	29	3.2	221
Reaming	6	31	28	7–84	23	2.3	133
Drilling	4	8	4	6–14	7	1.5	315
Cleaning	2	150	200	8–291	48	12.7	205

*Total n = 105. $F_{7,97} = 21.66$; $p < 0.0001$.

n, number of samples; AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation; MT, mean sampling time.

TABLE III. Task-Specific and Multi-Task Airborne Lead Level and Mean Sampling Period at a Bridge Rehabilitation Project, NYC 1993–1994

Task	n	AM ($\mu\text{g}/\text{m}^3$)	SD	Range ($\mu\text{g}/\text{m}^3$)	GM ($\mu\text{g}/\text{m}^3$)	GSD	MT (min)
Torch cutting	61	1,054	1,456	8–8,186	378	5.4	176
Scaling	77	833	1,006	8–5,080	373	4.3	167
Grinding	101	589	1,179	8–8,186	226	3.9	172
Rivet busting	117	560	796	10–3,854	231	4.1	189
Bolting up	56	131	274	7–1,499	52	3.5	258
Reaming	38	308	584	7–3,000	94	4.8	215
Drilling	33	262	628	6–3,100	52	5.5	274
Cleaning	9	268	342	8–1,096	101	5.6	190

n, number of samples; AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation; MT, mean sampling time.

Because of the skewed distribution of lead concentrations, geometric means, and standard deviations were computed in addition to their arithmetic counterparts. For those comparisons where each subgroup comprised a distinct set of air samples; i.e., for task-specific samples, an F-test from an analysis of variance was used to determine whether mean air concentrations differed by group (task). Statistic significance was assessed at the 0.05 level.

RESULTS

Bulk Sampling and Personal Monitoring

Five bulk samples were collected and analyzed for lead. Lead content of the paint ranged from 61.5% to 26.5%, with a mean of 39.1%. A total of 279 individual personal breathing zone samples were collected. The measured lead levels of these samples ranged from $2 \mu\text{m}^3$ to $8,186 \mu\text{m}^3$. The sampling period ranged from 10 to 424 min. Of the

279 samples, 105 are task-specific; i.e., the aerosol collected on the filter was generated during the performance of one task only. Descriptive statistics for the task-specific monitoring results are presented in Table II. Both the arithmetic and geometric mean concentrations as well as their standard deviations are presented; the mean sampling time is also shown. The results indicate that different tasks generate significantly different mean concentrations of leaded dust and/or fume ($F = 21.66$, $df = 7,97$, $p < 0.0001$). It is also evident that, for each task, there is a wide range of concentrations.

Table III presents the airborne lead level for samples where the measured concentration represents the performance of at least one task (task-specific), and sometimes several tasks (“multitask”). Multitask samples represent the collection of aerosol during periods when it was not possible to change the cassette when the worker changed his task. The total number of samples shown is greater than

TABLE IV. Operation-Specific Airborne Lead Level at a Bridge Rehabilitation Project, NYC 1993–1994*

Operation	n	AM ($\mu\text{g}/\text{m}^3$)	SD	Range ($\mu\text{g}/\text{m}^3$)	GM ($\mu\text{g}/\text{m}^3$)	GSD	MT (min)
Removing	144	885	1,217	10–8,186	411	3.8	142
Both (removing and installing)	68	331	584	8–3,100	132	3.9	223
Installing	48	38	44	6–286	26	2.3	210
Other	19	21	22	2–100	15	2.3	229

*Total n = 279.

n, number of samples; AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation; MT, mean sampling time.

TABLE V. Multitask 8-hr TWA Lead Level at a Bridge Rehabilitation Project, NYC 1993–1994

Task	n	AM ($\mu\text{g}/\text{m}^3$)	SD	Range ($\mu\text{g}/\text{m}^3$)	GM ($\mu\text{g}/\text{m}^3$)	GSD	MT (min)
Torch cutting	25	499	517	12–1,778	234	4.3	393
Scaling	26	402	481	14–2,020	202	3.5	396
Grinding	39	330	412	12–2,020	169	3.4	394
Rivet busting	42	326	428	8–2,020	149	3.8	394
Bolting up	30	138	182	6–665	64	3.7	400
Reaming	19	395	530	12–2,020	160	4.4	398
Drilling	19	205	462	5–2,020	46	5.8	394
Cleaning	4	210	356	12–744	63	5.8	398

n, number of samples; AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation; MT, mean sampling time.

the sum of the individual samples collected (279), since multitask samples are recorded at least twice. For example, data for torch cutting include measurements taken when torch cutting was the only task performed and when it was combined with other tasks for that measurement period. In Table III, the mean sampling time represents the period during which the sample was collected, and not the duration of any one task.

Operation-specific samples resulting from grouping the task-specific and multitask samples into one or another operation are presented in Table IV. In addition to the two operations defined earlier, a “both” category was added to account for individual samples during which a worker engaged in both removing and installing tasks. “Cleaning up” is included in the “both” category.

The 279 task-specific and multitask samples comprise 126 TWAs. The actual total sampling time was always less than, and often much less than, 8 hr. Since on any given day most workers worked ≥ 6 hr performing tasks that generated dust or fume, a decision was made to calculate 8-hr TWAs only for those exposures that represented a total sampling time of ≥ 360 min. The remainder of the shift (unsampled time) was spent gearing up for the work in the morning and putting tools away and washing up at the end of the shift, and 8-hr TWAs were calculated by assuming

“zero exposure” for the time not sampled. Of the 126 TWAs, 70 represented samples collected over ≥ 360 min. An 8-hr TWA was assigned to each task that was being performed during the collection of samples which comprise the TWA. Thus, if a worker performed torch cutting, grinding, and drilling during his shift, the resultant TWA was assigned once to each of these tasks. Table V presents these results.

OSHA's Presumed Exposure Levels

Presumed task-based exposure levels are addressed in two sections of the preamble to the OSHA Lead in Construction Standard [OSHA, 1993]. One section, entitled “Trigger levels,” analyzes the basis for the task-based exposure levels selected and the concomitant worker protection required. Table VI summarizes the levels selected by OSHA for three tasks and compares these to levels measured in the present study. OSHA presents data in three exposure ranges ($50 \mu\text{g}/\text{m}^3$ to $500 \mu\text{g}/\text{m}^3$, $500 \mu\text{g}/\text{m}^3$ to $2,500 \mu\text{g}/\text{m}^3$ and $>2,500 \mu\text{g}/\text{m}^3$) because these coincide with the protection factors assigned to different classes of respirators measured in terms of multiples of the Permissible Exposure limit (PEL) of $50 \mu\text{g}/\text{m}^3$, that is, 10 times, 25 times, and >25 times the PEL.

TABLE VI. OSHA's Presumed Levels for Selected Tasks Compared to Study Measurements

Task	OSHA's presumed level ($\mu\text{g}/\text{m}^3$)	Measured task-specific level ($\mu\text{g}/\text{m}^3$)
Rivet busting	500–2,500	10–1,200
Power tools for grinding and sanding (without dust collection systems)	500–2,500	9–5,509
Torch burning and cutting	>2,500	63–5,314

In another section of the preamble, OSHA presents task-based levels as part of a discussion of the regulatory impact and feasibility of the standard. Two of the tasks discussed by OSHA coincide with tasks performed during work at the study site. Table VII presents these data and compares them to those collected during the present study. OSHA presents the arithmetic mean concentrations as well as the 95% UCL, upon which worker protection is based. For these data, unlike those previously cited (Table VI), OSHA presents the number of measurements on which the data are based as well as the arithmetic mean, range, standard deviation, and 95% UCL. Because OSHA collapses individual tools (pneumatic grinder and scaler) into one category (“power tool”), data on “power tool use” is presented twice, once to compare to our data for pneumatic scaling and once to compare to pneumatic grinding. For this table, OSHA is ostensibly presenting 8-hr TWAs, whereas our data are task-specific measurements taken over the periods indicated in Table II.

DISCUSSION

Task-based personal monitoring for lead exposure at a bridge rehabilitation site was evaluated in terms of the usefulness of this approach to determining the need for and extent of worker protection. The exposure levels at this site were compared to the presumptive airborne task-based exposure levels adopted by OSHA in its 1993 Lead in Construction Standard.

The most important finding of this study is that the disaggregated task-based approach to exposure assessment yields specific data, very different from mean exposure levels, on which worker protection strategies can rationally be based. Task-specific exposure levels showed statistically significant differences among tasks (Table II). With the inclusion of multitask data (Table III), and the subsequent calculation of the 8-hr TWAs, appreciable differences still exist although the magnitude of the differences among tasks is less. A task-specific assessment provides a much clearer evaluation of the real hazards. This is most apparent when we compare the geometric mean exposures for each task as

presented in Tables II–IV. These differences have not been analyzed statistically, because, by definition, the collection of multi-task data precluded knowledge of both the contribution of any one task to the total exposure as well as the period of time during which a particular task was performed.

A word should be said here about the definition of “task.” In the few studies published to date on task-based exposure assessment, the term “task” is defined implicitly, by example, rather than explicitly [Hansen and Whitehead, 1988; Burkhart et al., 1993; Nicas and Spear, 1993; Susi and Schneider, 1993; Greenspan et al., 1995; Susi and Schneider, 1995]. The OSHA standard also does not define task, although it provides more than 30 examples of tasks. For purposes of this study, the task was defined by the tool used to perform the task, e.g., by the activity performed with the tool.

OSHA's task-specific data showed good agreement with our task-specific data (Table V). However, it is important to keep in mind that OSHA's task-specific data (at least ostensibly) represent 8-hour TWAs, whereas our data were collected over shorter time periods corresponding to the performance of the task.

Comparison of the data sets highlights several problems with OSHA's data, and some ambiguities in the standard. As mentioned previously, the task-based exposure presumptions are surrogates for actual measurements. However, there is no clear indication of the sampling strategy used to collect the data presented by OSHA. Since the data represent a collation from several sources, it is probable that there were several strategies at work. It is also unclear whether the data represent full shift, task-specific samples or whether they represent multitask samples as described above. Likewise, there is no indication of how the 8-hour TWAs were calculated—for example, whether workers were monitored for a full 8 hr and, if not, how much time was unsampled and how this time was dealt with in the 8-hr TWA calculation.

The lack of clarity in the preamble to the standard concerning the data also makes it difficult to interpret the worker protection requirements that are based on the data. When prescribing different levels of respiratory protection, for instance, the standard does not explicitly state whether performing a task at all, for any length of time, triggers a protection level, or whether the task has to be performed for the full shift before a particular level is mandated. The iron work tasks performed to rehabilitate a bridge, as described in this paper, are generally repeated time and again. However, there is a great deal of variability in the sequence in which tasks are performed and the extent to which tasks are performed alone or in combination with other tasks. The sequence will vary from site to site and, quite often, within the same site during different phases of a job or during different operations. The sequence of tasks is dependent upon factors such as the scope of the rehabilitation, the structure or part of the structure being rehabilitated, the time

TABLE VII. OSHA's Presumed Levels for Selected Tasks Compared to Measured Task-Specific Exposures

Task	OSHA				Study			
	n	AM ($\mu\text{g}/\text{m}^3$)	SD	95% UCL ($\mu\text{g}/\text{m}^3$)	n	AM ($\mu\text{g}/\text{m}^3$)	SD	95% UCL ($\mu\text{g}/\text{m}^3$)
Torch cutting	90	1,230	1,897	1,564	25	1,357	1,248	1,748
Power tool use ^a	65	735	2,794	1,314	11 ^b	989	773	1,407
					22 ^c	443	1,141	872

^aOSHA defines as "other paint removal projects."

^bPneumatic scaling.

^cPneumatic grinding.

AM, arithmetic mean; SD, standard deviation.

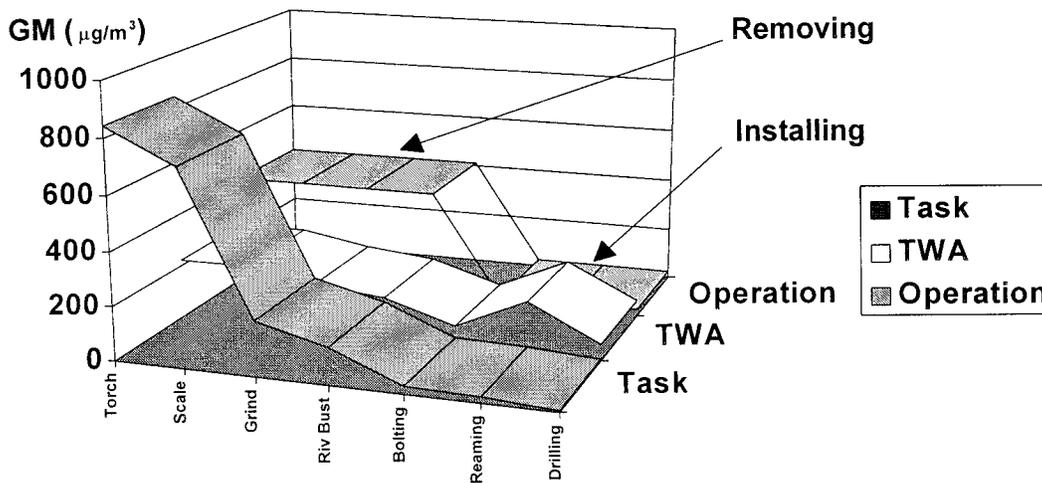


FIGURE 1. Airborne lead levels by task, operation and calculated 8-hr TWA at a bridge rehabilitation project, NYC, 1993–1994.

and money available to do the job, and the engineering design of the rehabilitation. The OSHA standard appears to address exposures occurring over a full shift.

The question must be addressed as to whether worker protection, at a work site where workers perform at least two and sometimes more tasks over a full shift, should be based upon the task-specific data, upon the full-shift or 8-hr TWA, or upon the operation-specific data. Our analysis has shown that the 95% UCL of the task-specific data reliably allow conclusions to be drawn about levels of worker protection that are in essential agreement with OSHA's recommendations. At the same time, our calculated 8-hour TWAs are a less reliable indicator of the need for such protection. Combining the exposures resulting from different tasks (e.g., task-specific and/or multitask samples), as was done in our calculation of the full-shift TWA, reduces the contribution of high exposure tasks and increases that of low exposure tasks. Thus, for instance, if we compare the 8-hr TWA data for "torch cutting" with those for "reaming" (Table V) they are very similar. However, we know from the task-specific data that the two represent the high and low ends of exposure.

As suggested above, one could base the areas to focus controls, or determine levels of worker protection, on the exposure levels reflected in the operation-specific data (Table IV). This approach offers the advantage of relative ease of personal monitoring, since the operation generally is spread over a longer time span than are the component tasks, and would require fewer sampling cassette changes during the sampling period. This is no small advantage to the industrial hygienist in the variable environment of bridge rehabilitation work. Also, since fewer samples would be collected, the analytical costs borne by the contractor would be reduced. It is clear that the operation-specific data better reflect the higher exposures evidenced in the task-specific data than do the 8-hr TWA's. Nonetheless, the same damping effect on high exposures is seen in the operation data. A comparison of the geometric mean exposures from task-specific, operation-specific and 8-hr TWA data (Fig. 1) clearly indicates these differences.

If one goal of exposure assessment for lead at bridge rehabilitation sites is to identify and control specific phases of the work which generate high exposures and to determine

the need for specific levels of worker protection, the damping effect of combining task-based data into operation-based exposure levels or calculated TWAs could lead to underestimating the protection workers require. We believe that worker protection can and should be determined by task-specific data, even when they are not full-shift. This conservative approach is based on the current lack of understanding of the effects which the rate of exposure and subsequent biological absorption have on the distribution, deposition, and target-receptor dose of lead. It is possible, for instance, that short-term peak doses associated with such tasks as torch cutting have a greater biological effect than equivalent doses resulting from much lower exposures over a longer period of time. Under such conditions, the biological integration of exposure variability might not follow models developed for lead and other contaminants with relatively long biological half-lives [Rappaport, 1985]. In addition to its chronic effects, lead does have well-known acute effects. We do not know, for instance, how lead is distributed biologically following extremely high exposures common, for instance, during torch cutting.

Another consideration that leads to a conservative approach to worker protection is based on the fact that particle size fractions are bound to be different for different tasks [ACGIH, 1989]. Torch cutting, for instance, typically produces fume of very small particle size, whereas tasks like scaling produce, on average, larger particles. Two studies that looked at the effects of particle size distribution upon biological absorption of lead in lead-using industrial operations emphasized that the distribution associated with different operations was critical for estimating the relationship between lead exposure and absorbed dose [Froines et al., 1986; Hodgkins et al., 1990]. Based on one of these studies, it seems likely that the fume exposures experienced by workers performing torch cutting is likely to lead to greater alveolar particle deposition, with subsequent greater systemic absorption than that predicted by the exposure-dose model which is the scientific basis of the OSHA lead standard [Froines et al., 1986; OSHA, 1978].

Bulk samples taken at different areas of the site where work was conducted indicate that, in general, there is a high percentage of lead by weight in the paint. Variability in the lead content is presumed to be due largely to four factors: (1) analytical variability; (2) all parts of the structure were not painted at the same time or with the same batch of paint; (3) paint formulations were not always consistent as to the percentage of the individual components, including lead; and (4) in certain parts of the bridge, one or several layers of tar were applied between paint layers as additional corrosion control. No attempt was made to correlate percent lead by weight in the paint with worker exposures.

The range of the data collected for each task is large. In this paper we did not assess the possible causes of the variability. Although the two basic operations of removing

steel and paint, and attaching new steel were performed repetitively from the under-bridge platforms, the conditions under which they were performed were constantly changing. The changes depended upon such factors as: the phase of the work (i.e., mostly removal and cleaning or mostly attaching); the condition of the coating on the steel (extent of corrosion and paint delamination from subsurfaces); the location of the work relative to the structure (degree of worker enclosure); the number of workers active in close proximity to each other and the tasks they were performing; and environmental conditions (e.g., wind direction and speed). We hope to address the potential contributors to this variability in future papers, using a task-based exposure assessment methodology.

CONCLUSIONS

When conducting exposure assessment at construction sites, the industrial hygienist is faced with unique conditions not often found in industrial workplaces. The traditional approach to worker monitoring, which relies heavily on full shift monitoring independent of a worker's tasks, could easily lead to underestimating the consequence of peak exposures.

The development of an exposure assessment strategy in construction should be based upon specific knowledge of the project, the trade or trades at work, and the tasks being performed. The OSHA Lead in Construction Standard correctly highlights the crucial role that task plays in determining worker exposure. We have found in the analysis that, in the bridge rehabilitation sector, a successful assessment strategy must take into account such factors as the scope of the work, the complexity of the structure, the number of workers employed, the time allotted for the job, and the engineering design of the rehabilitation. Important allies for the industrial hygienist in developing a strategy are the engineers responsible for the work and the workers themselves who have intimate knowledge of how tasks will be sequenced and when operations will be performed.

To be sure, much more work has to be done to refine the task-based approach, and to test its validity as a method for assessing exposures and recommending controls. Nonetheless, whether one conducts exposure assessment for determining contractor compliance or for developing worker protection programs, a task-based approach shows promise as a method for capturing both the range of, and the highest exposures in, the complex dynamic environment of a construction site.

Ultimately, a key goal of the task-based approach is to lessen the burden of exposure assessment in the construction industry by developing extensive databases in which tasks, their associated exposure levels, and site-specific determinants of exposures are presented. With such databases at hand, industrial hygienists, contractors and project owners

could determine, with perhaps a limited amount of additional monitoring, the best strategy to reduce exposures and protect workers.

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REFERENCES

- American Conference of Governmental Industrial Hygienists (ACGIH) (1985): "Particle Size Selective Sampling in the Workplace: Report of the ACGIH Technical Committee on Air Sampling Procedures. ACGIH (1985), Cincinnati, OH.
- Burkhart G, Schulte PA, Robinson C, Sieber WK, Vossen P, Ringen K (1993): Job tasks, potential exposures, and health risks of laborers employed in the construction industry. *Am J Ind Med* 24:413-425.
- Froines JR, Liu WV, Hinds WC, Wegman DH (1986): Effect of aerosol size on the blood lead distribution of industrial workers. *Am J Ind Med* 9:227-237.
- Goldberg M, Susi P, Jerziorowski L (1995): "Toward the development of an integrated approach to worker protection during industrial lead operations." Steel Structures Painting Council: Eighth Annual Lead Paint Abatement and Removal Conference.
- Greenspan CA, Moure-Eraso R, Wegman DH, Oliver CL (1995): Occupational hygiene characterization of a highway construction project: A pilot study. *Appl Occup Environ Hyg* 10:50-57.
- Hansen DJ, Whitehead, LW (1988): The influence of task and location on solvent exposures in a printing plant. *Am Ind Hyg Assoc J* 49:259-265.
- Hodgkins DG, Hinkamp DL, Robins TG, Levine SP, Schrorck MA, Krebs WH (1990): Air-lead particle sizes in battery manufacturing: potential effects on the OSHA compliance model. *Appl Occup Environ Hyg* 5:518-525.
- Nicas M, Spear RC (1993): A task-based statistical model of a worker's exposure distribution. Part II. Application to sampling strategy. *Am Ind Hyg Assoc J* 54:221-227.
- NIOSH (National Institute for Occupational Safety and Health) (1992): NIOSH Alert: Request for Assistance in Preventing Lead Poisoning in Construction Workers. DHHS (NIOSH) Publ No. 91-116a.
- Rappaport SM (1985): Smoothing of exposure variability at the receptor: Implications for health standards. *Ann Occup Hyg* 29:201-214.
- Ringen K, Englund A, Seegal J (1995): Safety and health in the construction industry. *Annu Rev Public Health* 16:165-188.
- Susi P, Schneider S (1993): "Chemical Exposures on a New Construction Site." Occupational Health Foundation. Washington, DC.
- Susi P, Schneider S (1995): Database needs for a task-based exposure assessment model for construction. *Appl Occup Environ Hyg* 10:394-399.
- U.S. Department of Labor, Occupational Safety and Health Administration, Occupational Exposure to Lead (1978): Fed Reg, Vol. 43, No. 220—Tuesday, Nov. 14, 1978.
- U.S. Department of Labor, Occupational Safety and Health Administration, 29 CFR Part 1926: Lead Exposure in Construction; Interim Final Rule (1993): Fed Reg, Vol. 58, No. 84—Tuesday, May 4, 1993.