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Metal Exposure Among Abrasive Blasting Workers at Four U.S. Air Force Facilities

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Button Aerosol Samplers were used to monitor the personal exposure of workers performing abrasive blasting operations at four U.S. Air Force facilities. Inhalable aerosols containing 25 metals, including cadmium, lead, and chromium, were investigated. The Button Aerosol Sampler was chosen because of its ability to successfully withstand mechanical stress, prevent very large particles from collection, and protect the filter from overloading and shredding by rebound particles. In addition, previous studies have shown that the sampling efficiency of this personal Aerosol Sampler exhibits low sensitivity to the ambient air conditions and that it adequately follows the inhalability convention. Inductively coupled plasma (ICP) was used to analyze the collected samples for all 25 metals. In addition, visual absorption spectrophotometry (VAS) was used to analyze for hexavalent chromium because of the presence of strontium chromate. The collected samples yielded 8-hr time-weighted average (TWA) concentrations that were up to 250, 6, and 5 times higher than the permissible exposure limits (PELs) for cadmium, lead, and hexavalent chromium, respectively. Also, the chromium levels measured by the ICP and VAS exceeded the strontium chromate threshold limit value (TLV®) by up to 640 and 950 times, respectively. No correlation was found between the ICP and VAS hexavalent chromium concentrations. The likely reasons of this were the presence of Cr (II) and (III) that cannot be detected by the VAS, and the chemical interference from iron and some other metals in the samples. The Button Aerosol Sampler was shown to be useful for the monitoring of workers' exposure to heavy metals during abrasive blasting operations.

Keywords Abrasive Blasting, Heavy Metal Exposure, Button Aerosol Sampler

Abrasive blasting is a common method of corrosion control and surface preparation that generates vast amounts of airborne dust. This dust is the most serious occupational health hazard associated with a typical abrasive blasting operation.(1) Depending on the surfaces being blasted, the presence and nature of prior coatings, and the abrasive media used, the dust may contain high levels of different toxic substances, including crystalline silica and heavy metals such as lead, cadmium, chromium, and their compounds.(2–4)

Occupational exposure to free crystalline silica may produce silicosis and pulmonary fibrosis.(5) Short-term inhalation exposure of adults to lead may cause damage to the gastrointestinal tract, blood (anemia), CNS (encephalopathy), and kidney. Long-term or repeat exposure to lead may cause irreversible nephropathy, paralysis of the muscle groups of the upper extremities, disorders of the immune and reproductive systems, and personality changes in extreme cases.(6) Short-term inhalation exposure to cadmium may cause irritation of the eyes and the respiratory tract, pulmonary edema, diarrhea, and anemia. Long-term or repeated exposure to cadmium may cause kidney damage (proteinurea).(6) Short-term inhalation exposure to hexavalent chromium—for example, strontium chromate—may irritate the eyes and cause liver and respiratory tract injury. In the long-term, it may cause skin (chrome ulcers) as well as blood, liver, kidney, and CNS damage.(6) In addition, cadmium and strontium chromate are classified as A2 (suspected human) carcinogens; other hexavalent chromium compounds are classified as A1 (confirmed human) carcinogens.(7) Thus, given the abundance of potential respiratory health hazards generated during abrasive blasting, their adequate evaluation is essential for the implementation of effective controls to ensure workers' protection.

Evaluation of worker exposure during abrasive blasting requires the use of personal Aerosol Samplers. The 25- and 37-mm filter cassettes (e.g., SKC Inc., Eighty Four, PA) are commonly used in industrial hygiene particulate air sampling applications, including abrasive blasting monitoring. They were designed to collect the total fraction of the airborne dust(8) for the gravimetric analysis of the sample according to NIOSH Method No. 0500.(9) However, their sampling efficiencies are not 100 percent for all particle sizes under all wind velocity and orientation conditions. Because abrasive blasting is a health hazard to the human respiratory tract, we consider particle size-selective sampling to be more appropriate than sampling for total dust. We chose to sample the inhalable aerosol fraction(7) because particles generated during abrasive blasting may affect the entire respiratory tract. The aerosol sampling efficiencies of the 25- and 37-mm filter cassettes are significantly lower than the inhalable sampling convention,(10,12) particularly for particle sizes above 20 μm.(12) Thus, due to their low sampling efficiency, the filter cassettes may significantly underestimate the workers' exposure to airborne metals.

The development of personal inhalable Aerosol Samplers was a significant technological achievement. One of the most notable examples of these is the IOM sampler (SKC Inc., Eighty Four, PA).(13) Its sampling efficiency matches the inhalability convention well.(11,12) However, the IOM sampler has not been utilized widely in abrasive blasting environments. The primary reason is because its large, 15-mm open inlet does not protect the filter from rapid overloading and/or shredding by high-velocity particles projected directly into the inlet after rebounding from surfaces being blasted. Similar effects were also observed when using closed-face 37-mm filter cassettes.(14) In addition, particles larger than 100 μm (i.e., larger than the currently established upper limit of the inhalable range) are abundant during abrasive blasting and are easily captured by the IOM sampler as well as the 25- and 37-mm filter cassettes. While particles larger than 100 μm have less than 50 percent probability of being inhaled by a worker, a few of these particles on a filter will outweigh all the other "inhalable" particles combined. Also, these very large particles often become a subject of laboratory elemental analysis due to the absence of guidelines on the sampling of non-inhalable dust. This may result in considerable overestimation of the workers' exposure to airborne metals. It has been shown that these large particles may contain over 95 percent of the total metal content of a sample.(15)

Some attempts have been made to address these issues. Aitken and Donaldson(16) used cylindrically shaped mesh screens to shield the inlet of the IOM sampler when it was exposed to very large particles. Sylvain(17) outfitted 37-mm cassettes with several kinds of protective screens and also experimented with different sampler mounting locations on workers, including behind the head. These and other approaches have had only limited success.

Thus, one of the main problems encountered by industrial hygienists sampling aerosols generated by abrasive blasting operations is how to sample according to the inhalable convention with a sampler that can intercept very large particles and can withstand the mechanical stresses produced by this extremely aggressive environment.(13)

In this study we used the Button Aerosol Sampler (SKC Inc., Eighty Four, PA). This sampler (Figure 1) has been shown to

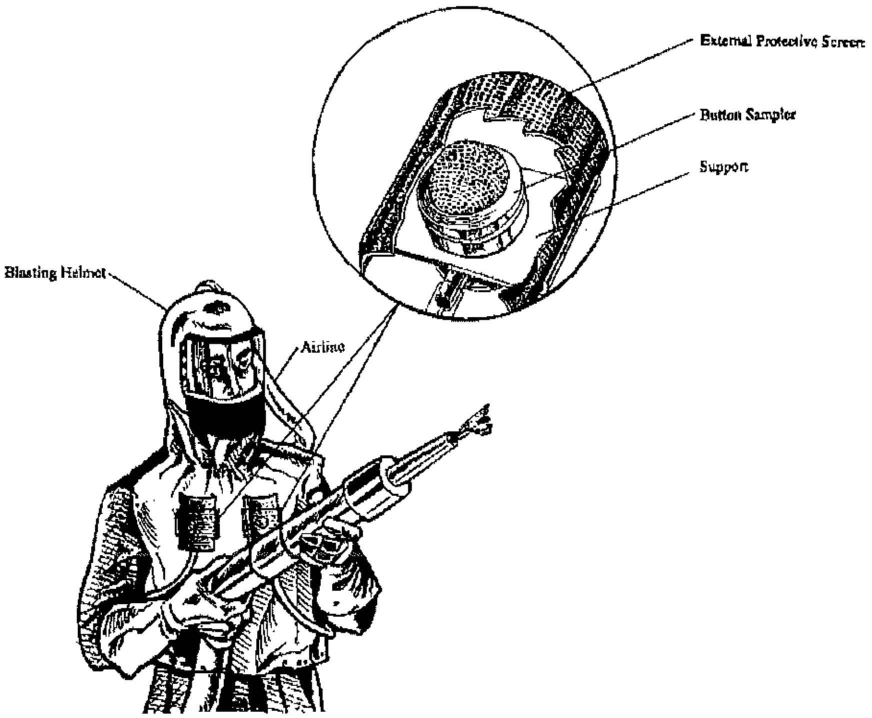

FIGURE 1
Button Aerosol Samplers on an abrasive blasting worker.

follow the inhalability criterion similar to or better than other commonly used inhalable Aerosol Samplers and to meet most other requirements for personal aerosol sampling.(18) Its stainless steel inlet has a curved porous surface that is part of a sphere with a subtended angle of 160 degrees. The surface contains numerous orifices of 381 μm diameter that are evenly spaced. The resultant porosity is 21 percent. The porous inlet not only protects the sampler's 25-mm filter from mechanical damage, but also intercepts virtually all projected particles above approximately 150 μm in size. The Button Aerosol Sampler has been shown to have low sensitivity to wind direction and velocity, good uniformity of particle collection on its filter, and low intersample variability.(19–22)

METHODS

The field measurements for this study were performed at four U.S. Air Force facilities which will be referred to as sites A, B, C, and D. At all four sites, abrasive blasting was conducted in enclosed, walk-in blast facilities with cross-draft ventilation. The typical distance between a worker and a surface being blasted was 12 to 18 inches (0.30 to 0.45 m).

All workers wore type CE abrasive-blast supplied-air respirators, primarily W-8100 (3M Inc., St. Paul, MN) and 88 series (Bullard Inc., Cynthiana, KY) continuous flow respirators with a blasting helmet (Figure 1). Both models have the assigned protection factor (APF) of 2000 for lead environments (29 CFR 1910.1025 and 29 CFR 1910.134). For cadmium, chromium, and most other metals in general industry environments, the APF is 25 (29 CFR 1910.134, 29 CFR 1910.1027 and NIOSH(23)). However, ANSI standard Z88.2-1992 designates an APF of 1000 for these respirator models.(24) Grade D clean air was supplied to the workers through an airline as required by 29 CFR 1910.134(i).

The parts being blasted were either aircraft parts (stabilizers, wheels, canopy frames, and landing gear components) or aerospace ground equipment. They were made of different materials, primarily steel, aluminum, and advanced composites. Some of the surfaces being blasted were covered with old primer, paint/plating, or both. Therefore, different types of abrasive media were used to match the part material. Due to the variety of parts being blasted and the abrasive media used, all of the observed tasks were subdivided into 10 categories for the purpose of analysis, regardless of the site where the blasting occurred (see Table I). The classification presented in Table I is not perfect because some of the big parts being blasted sometimes had subsections made of different materials. This observation is especially relevant when assessing exposure to cadmium, because rivets or small cadmium-plated sections were present during tasks other than task category 4.

Five Button Aerosol Samplers were used to measure the personal exposures to heavy metals of workers involved in abrasive blasting operations. Each sampler was equipped with an additional external curved protective screen, measuring 4 by 2.5 inches (10 by 6.4 cm). Each sampler and external protective screen were mounted on a custom-made support (Figure 1). The external protective screens were made of the same material as the Button Sampler's inlet screen (i.e., stainless steel having 21% porosity with 381-μm orifices). The distance between the external screen and the Button Sampler inlet screen was about 1 inch. Since 79 percent of both screens is impervious, the screens act as shields against high-inertia particles generated during the abrasive blasting and projected toward the sampler. The orifices of 381-μm diameter in the screens are large enough to pass lower-inertia particles of size considerably smaller than the diameter of the orifices. Thus, the external protective screen and the Button Aerosol Sampler's inlet screen prevented the rapid overloading of the filters by large particles, while not interfering with the collection of smaller particles. The majority of samples were collected at the flow rate of 4 L/min recommended by the manufacturer. However, several samples at site A were collected

TABLE I
Abrasive blasting tasks observed

Task category	Material	Primer	Paint or plating	Blast media	Number of samples[A]	Site(s)
1	Steel	No	No	Glass bead	4/5	A
2	Steel	No	No	Aluminum oxide	3/4	A
3	Steel	Yes	Yes	Glass bead	14/21	D
4	Steel	Yes	Yes[B]	Plastic	4/3	B
5	Steel	Yes	Yes	Plastic	17/17	B,C
6	Graphite composite	Yes	Yes	Plastic	4/5	A
7	Aluminum	Yes	Yes	Walnut shell	1/1	A
8	Aluminum	Yes	No	Plastic	9/9	B
9	Aluminum	Yes	Yes	Plastic	6/7	C
10	Aluminum	No	No	Plastic	5/5	C

[A] Number of samples analyzed by NIOSH Method 7300/Number of samples analyzed by NIOSH Method 7600.

[B] Cadmium Plating. Cadmium-plated rivets or small cadmium-plated sections were present during other tasks.

at 3 L/min because of problems with the personal sampling pumps.

Among the 25 elements analyzed in this study, lead, cadmium, and chromium were of primary interest. Prior studies had established that chromium is present mainly in the hexavalent form. It was contained as strontium chromate in the epoxy primer and as a chromic acid solution in the anticorrosive alodine coatings of some aluminum parts.(14) A small percentage of chromium may also have been present as Cr (II) and Cr (III) compounds that are frequently present in the environment.

Two approaches were used to measure airborne chromium. In the first approach, the aerosol particles were sampled onto membrane cellulose ester (MCE) filters followed by ICP analysis for all 25 heavy metals. The ICP analysis was performed according to NIOSH Method 7300,(25) which detects chromium (II), (III), and (VI) as total chromium. It was assumed that the total chromium reading was generally due to strontium chromate, although the presence of some chromium (II) and (III) was anticipated. This assumption was validated during prior experiments.(26) The second approach was to sample onto polyvinyl chloride (PVC) filters that were analyzed using VAS in accordance with NIOSH Method 7600,(25) which allows specific detection of hexavalent chromium. In this case, the assumption was that the entire hexavalent chromium reading was due to the presence of the strontium chromate. Two identical Button Aerosol Samplers were placed simultaneously in each worker's breathing zone, on both sides of the body outside of the personal protective equipment, as shown in Figure 1. This arrangement conforms to 29 CFR 1910.94 (a)(2) and other Occupational Safety and Health Administration (OSHA) guidelines.(27) Thus, each experiment normally yielded two samples exposed to the same concentrations of the airborne contaminants. Unfortunately, some of the experiments yielded only one sample, with the second one lost for a variety of reasons, including pump failure or the worker's unintentional interference with a sampler.

The monitored workers were typically engaged in abrasive blasting for short periods of time lasting between 10 and 45 minutes. These time intervals were preceded and followed by other tasks during which little or no hazardous dust was generated (e.g., part masking, part positioning, rest breaks, etc.). The Button Sampler filters were replaced during these low-exposure tasks. However, the workers were monitored during the entire shift. The typical overall duration of abrasive blasting activities was six hours at sites A, B, and C, and four hours at site D. The time periods during which no abrasive blasting was performed were treated as having zero exposure for the purpose of calculating the eight-hour time-weighted average (TWA) concentration.

RESULTS AND DISCUSSION

Figures 2A and B and 3A and B present the results of air sampling, converted to the mean 8-hour TWA concentrations for cadmium (Figure 2A), lead (Figure 2B), and hexavalent chromium (Figures 3A and B). Figures 3A and 3B present the air sampling results analyzed according to NIOSH methods 7300 and 7600, respectively. The corresponding permissible exposure limits (PELs) for cadmium, lead, and chromium (II), (III), and (VI) are also shown in these figures. Figures 3A and 3B also show the threshold limit value (TLV®) for strontium chromate. The TWAs are given for each of the work task categories described in Table I. The standard errors of the mean for the TWA of each task are also shown, based on the number of samples taken (see Table I). In the case of task category 7, no standard error is shown because only one sample was taken.

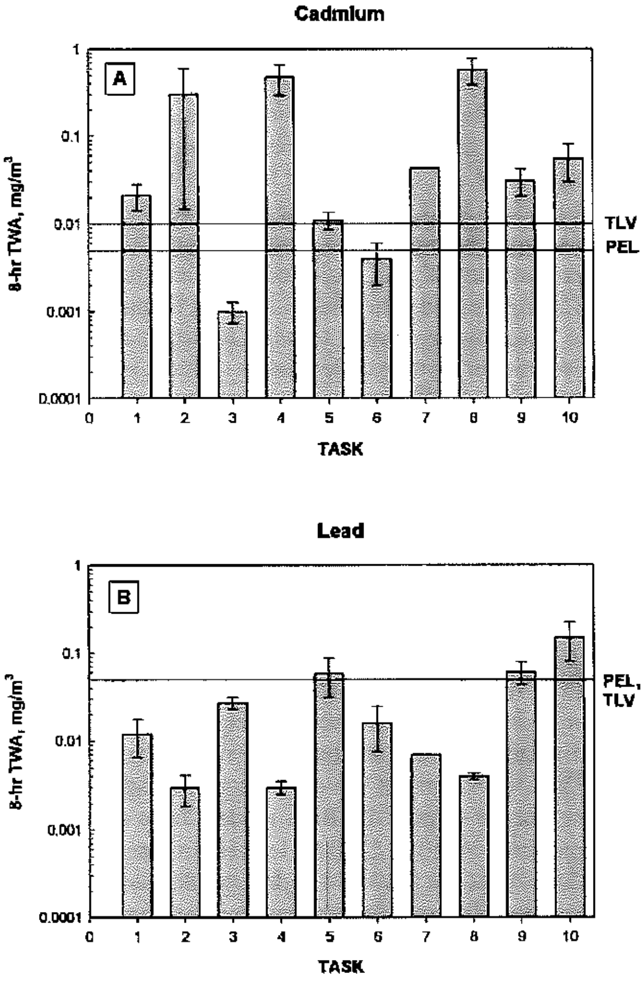

FIGURE 2

Eight-hour TWA concentrations. A. Cadmium by ICP. B. Lead by ICP.

The considerable variability of data shown in Figures 2A and B and 3A and B is in line with that of other studies. Table II compares the coefficients of variation (CV) for lead and chromium TWAs from our study with the data from two independent studies.(15,17) The earlier studies utilized 37-mm filter cassettes for the personal exposure measurements. Each coefficient of variation was determined as the ratio of the sample standard deviation to its mean. The CVs determined in this study represent the range from the lowest to the highest ratios among 10 different tasks. The cadmium data obtained in this study were

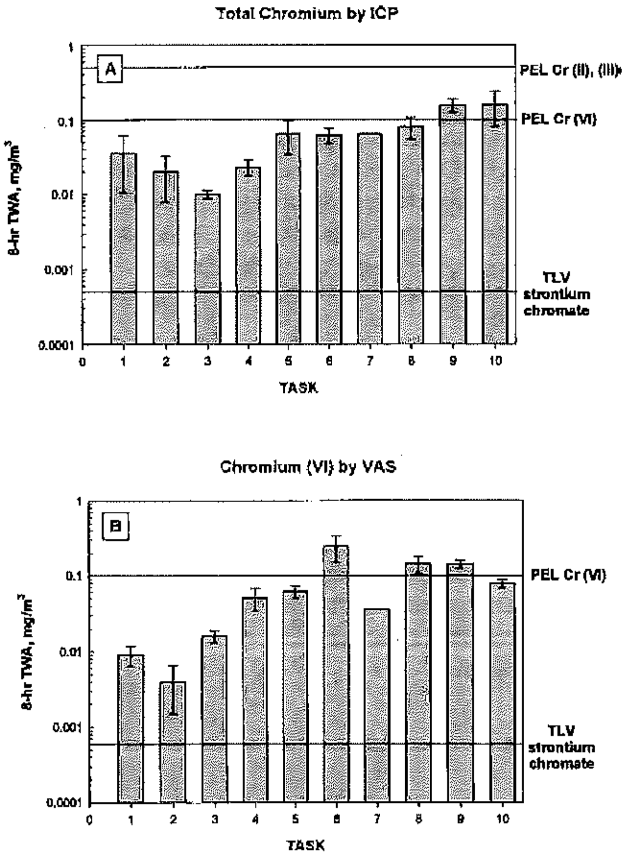

FIGURE 3
Eight-hour TWA concentrations. A. Chromium by ICP. B. Chromium by VAS.

not included in Table II, because both of the earlier studies did not involve cadmium. Also, because both earlier studies used ICP analysis, Table II lists only the chromium data obtained by ICP (Figure 3A). The CV values obtained in our study for the lead and chromium TWAs are comparable to those of the earlier studies.

As seen from Figure 2A, tasks 2, 4, and 8 yielded the highest mean cadmium TWA concentrations. As expected, workers performing task 4 were exposed to high cadmium levels because of the presence of large cadmium-plated parts (see Table I). More interesting was the finding of high cadmium levels during tasks 2 and 8. We attribute these higher levels to the presence of several small cadmium-plated subsections and rivets that were difficult to identify prior to blasting. Overall, the measured 8-hr TWA airborne cadmium concentrations were higher than the PEL of 0.005 mg/m^3 for nine out of ten tasks. The airborne cadmium mass concentrations exceeded the TLV of 0.01 mg/m^3 for the inhalable fraction during eight out of ten tasks.

The TWA concentrations for lead (Figure 2B) were found to be mostly below the PEL and TLV values, both of 0.05 mg/m^3, with the exception of tasks 5, 9, and 10.

During all tasks, the airborne 8-hr TWA concentrations of total chromium exceeded the strontium chromate TLV of 0.0005 mg/m^3 by a factor of 15 to 400 (Figure 3A). At the same time, the highest total chromium levels that exceeded the Cr (VI) PEL of 0.1 mg/m^3 were detected only in four tasks (5, 8, 9, and 10). No task produced total chromium concentrations in excess of the Cr (II) and (III) PELs of 0.5 mg/m^3. The hexavalent chromium 8-hr TWA concentrations (Figure 3B), exceeded the strontium chromate TLV by 10 to 600 times for all tasks observed. Tasks 5, 6, 8, 9, and 10 had shown the highest concentrations exceeding the hexavalent chromium PEL.

An analysis of correlation was conducted between total chromium (determined by ICP, NIOSH Method 7300) and hexavalent chromium (determined by VAS, NIOSH Method 7600). The correlation analysis was conducted on 66 experiments that yielded both hexavalent and total chromium data. Table III presents the correlation coefficients for each of the 10 tasks and the overall correlation coefficient. There is no correlation between the two sets of data: the overall correlation coefficient was found to be 0.20 (its *p*-value was 0.11 on 64 degrees of freedom, that is, the correlation coefficient observed was not significantly different from zero). This means that the high concentration values of the first data set (total chromium) do not correspond with the high concentration values of the second data set (hexavalent chromium). One of the reasons for this lack of correlation is the considerable amount of airborne chromium (II) and (III)

TABLE II
Comparison of the coefficients of variation of air sampling data from three studies

	This study		Sylvain, 1994		Kiefer et al., 1997	
CV, %	Pb	Cr	Pb	Cr	Pb	Cr
	25–175	44–142	168	120	118	64

TABLE III
Coefficients of correlation between total chromium[A] and hexavalent chromium[B] concentrations

Task	Coefficient of correlation
1	−0.49
2	−0.34
3	0.01
4	0.65
5	0.19
6	−0.91
7	N/A
8	0.26
9	−0.36
10	0.54
Overall	0.20

[A] Analyzed by ICP, NIOSH Method 7300.
[B] Analyzed by VAS, NIOSH Method 7600.

that is identifiable by the ICP, but not identifiable by the VAS. Another possible reason is interference by other heavy metals that may have decreased the Cr (VI) reading due to electron reduction.(28) Iron was the most prevalent of these interfering metals, although copper, nickel, and vanadium were also detected. The 8-hr TWA concentrations of airborne iron during the 10 observed tasks were as high as 3.32 mg/m^3, with the typical TWA concentration in the range of 0.05–0.2 mg/m^3. In addition, although both samplers were mounted close to each other in the workers' breathing zones, the workers' postures, movements, and equipment may have exposed the two samplers to different aerosol concentrations. As a result, the average total chromium concentrations for each task were not always higher than average hexavalent chromium concentrations, as one might have expected. For tasks 3, 4, 6, and 8 the VAS data were higher than the ICP data.

Our data show that the continuous flow supplied-air abrasive blast respirators satisfied the needs for respiratory protection against lead, according to the OSHA-designated APF of 2000 for lead environments. Because this APF is not valid for the protection against other metals (for which the APF is 25), it appears that the airborne cadmium and strontium chromate levels were above the respective maximum allowed concentrations. However, based on the ANSI APF of 1000, the protection can be deemed sufficient. Our conclusion regarding the adequacy of respiratory protection at the four sampled sites may have to be modified after OSHA makes it final rule on the APF of continuous-flow abrasive blasting helmets.

Button Samplers equipped with the external protective screens have successfully withstood the stress of sampling: of the five Button Aerosol Samplers used in this study none was damaged.

CONCLUSIONS

This study was undertaken to generate more definitive data on the exposure of workers to hazardous particulates, such as heavy metals generated during abrasive blasting. In the past, total dust samplers such as 25- or 37-mm sampling cassettes have been used for personal aerosol sampling. These samplers do not meet the inhalability convention that describes the penetration of dust particles into respiratory airways of humans. In addition, most available total and inhalable Aerosol Samplers cannot prevent very large particles from entering the sampler, thus skewing the sampling results toward significant overestimation of the airborne concentration of the metals of interest. Also, these samplers cannot protect their filters from shredding by high-velocity rebound particles. Therefore, the recently developed button Aerosol Sampler was used in this study to monitor the exposure of workers to 25 metals, including cadmium, lead, and chromium.

Based on the measured aerosol concentration levels and the ANSI-designated assigned protection factor of 1000, the respirators met the needs for respiratory protection against cadmium, lead, and hexavalent chromium. However, airborne cadmium and hexavalent chromium levels were above those satisfying current OSHA APF of 25.

The airbome chromium samples analyzed by the ICP spectrometry did not correlate with the data analyzed by VAS. This was attributed to a contribution of Cr (II) and (III) in the samples in addition to strontium chromate, which is a form of Cr (VI). The ICP technique can detect all three forms of chromium, while the VAS analysis identifies only hexavalent chromium.

The Button Aerosol Sampler mounted under an external protective screen was found to be adequate for the monitoring of aerosols during high-pressure abrasive blasting.

DISCLAIMER

The views expressed in this article do not necessarily reflect the views of the U.S. Air Force. Mention of brand names does not constitute endorsement by the Air Force.

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