Evaluation of Air Sampling Methods for Abrasive Blasting – Louisiana

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Acknowledgments

Abbreviations

µm	Micrometer
BAS	Button Aerosol Sampler®
HHE	Health hazard evaluation
LOD	Limit of detection
Lpm	Liters per minute
mg	Milligram
mg/m^3	Milligrams per cubic meter
mm	Millimeter
NIOSH	National Institute for Occupational Safety and Health
NAICS	North American Industry Classification System
OSHA	Occupational Safety and Health Administration
PBZ	Personal breathing zone
PPE	Personal protective equipment

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation at a shipyard in Louisiana. Shipyard managers asked investigators to compare methods for collecting personal breathing zone air samples for particulates during abrasive blasting. Abrasive blasting is the cleaning or finishing of surfaces by the use of an abrasive carried in a strong current of air.

What NIOSH Did

- We took air samples at the shipyard. Samples were collected during outdoor abrasive blasting where coal slag was used.
- We used a 37-millimeter diameter filter cassette and both an unshielded and a shielded button aerosol sampler to collect side-by-side personal breathing zone samples. These devices were connected to air sampling pumps.
- We also used the same sampling devices, without an air sampling pump, to collect personal breathing zone samples.
- We measured total dust and inhalable dust. We analyzed the particle size of the dust.

What NIOSH Found

- All three sampling methods collected too much particulate. This is called overloading.
- The 37-millimeter diameter filter cassettes collected a few large particulates.
- Overloading happened when the sampling devices were connected to an air sampling pump and when they were not.
- Overloading caused frequent sampling pump failures.
- Sampling pumps often disconnected or turned off as a result of the harsh abrasive blasting environment.

What NIOSH Concludes

- Sampling methods that can withstand the harsh abrasive blasting environment have not been developed.
- Sampling methods that do not overload and prevent large particulate from entering the device have not been developed. This is needed for accurate measurements of employee exposures during abrasive blasting operations.

Summary

NIOSH received a request for an HHE from the management at a Louisiana shipyard to evaluate sampling methods for measuring employee PBZ exposures during abrasive blasting. On July 20, 2001, NIOSH investigators collected side-by-side PBZ air samples using three types of commercially available sampling devices: a closed-face 37-mm cassette, an unshielded BAS, and a shielded BAS. For each type of sampling device we collected an "active" PBZ sample that was connected to an air sampling pump and a "passive" PBZ sample that was not connected to an air sampling pump. These active and passive samples were collected side-by-side for the duration of the abrasive blasting activity (approximately 60 to 80 minutes). Samples were used to evaluate whether inertia-driven abrasive material could enter the sampler during abrasive blasting. All of the air samplers were positioned outside the employees' abrasive blasting helmet following OSHA sampling guidance. Total dust was measured for the 37-mm filter samples. Inhalable dust was measured for the unshielded and shielded BAS samples.

NIOSH evaluated three PBZ air sampling methods during abrasive blasting operations at a shipyard. We found overloaded air sample filters for all three methods, which caused frequent failures of the air sampling pumps. We concluded that improved sampling methods were needed to accurately measure employee exposures during abrasive blasting operations.

The harsh and dusty abrasive blasting environment caused frequent sampling pump failures. Because of the failures, there was insufficient data for a statistical comparison of the air sampling results for the three sampling methods. All 37-mm cassette samples contained inertia-driven (loose) abrasive grit particles that accounted for up to 99% of the total particle weight. All unshielded and shielded BAS samples contained loose particulate. BAS total weights exceeded the recommended maximum sample loading of 2 mg. Some of the passive samples collected a similar amount of particulate as the active samples.

We concluded that none of the sampling methods we used performed reliably in an abrasive blasting environment. All were likely to overestimate air concentrations because of the presence of inertia-driven particulate in the samplers. Improving the design of sampling devices or developing alternative sampling methods is needed to accurately and reliably assess PBZ dust exposure concentrations during abrasive blasting operations.

Keywords: NAICS 336611 (Ship Building and Repairing), abrasive blasting, air sampling, button aerosol sampler, abrasive blasting sampler, total particulate, inhalable particulate.

Introduction

On July 20, 2001, we responded to a request for an HHE from the health and safety manager at a shipyard. The manager was concerned with the accuracy of particulate sampling methods for abrasive blasting. Current OSHA sampling and analytical methods can overestimate worker exposures to airborne metals and other particulate contaminants during abrasive blasting [NIOSH 1994,1998; OSHA 2012a]. The objectives of this HHE were to compare three commercially available sampling devices in an abrasive blasting environment and to evaluate whether a protective shield designed for one of the sampling devices prevented inertia-driven particles from entering and possibly overloading the sampler.

Background

Abrasive Blasting

Abrasive blasting utilizes pneumatic or hydraulic pressure or centrifugal force to direct a blast of abrasive material (wet or dry) to clean a surface, remove burrs, or impart a surface finish. Many abrasive blasting methods use either manual or automatic equipment [Clayton and Clayton 1978]. Metallic (e.g., steel shot) and non-metallic (e.g., coal slag, walnut shells) abrasives can be used. Because large quantities of dust can be generated, shipyard abrasive blasting is typically conducted within a ventilated enclosure.

Employees conducting shipyard abrasive blasting are exposed to safety hazards (e.g., rebound shot, high-pressure discharge, falls) and health hazards (e.g., inhalable airborne particulates, noise). OSHA has established regulatory requirements for ventilation, enclosures, and PPE during abrasive blasting [OSHA 2012b]. Type CE airline respirators, required for work inside blast-cleaning enclosures, are equipped with head, neck, and upper body coverings to protect employees from rebounding abrasive blasting material [NIOSH 1987].

Sampling Issues

Previous studies have shown that PBZ sampling during abrasive blasting using 37-mm cassettes can overestimate exposure to non-inhalable particulate because large inertia-driven particulate can enter the sampling cassettes [NIOSH 1994, 1998]. New or improved sampling methods are needed to evaluate PBZ exposure during abrasive blasting. Some alternative air sampling methods that have been suggested for exposure monitoring during abrasive blasting include shielding the 37-mm filter cassette inlet to exclude non-inhalable particles, mounting the PBZ air sampler behind the employee's head to protect the sampler from rebounding abrasive materials, and using the Institute of Medicine inhalable dust sampler. None of these alternatives has been found to be practical or effective in abrasive blasting environments [NIOSH 1994,1998]. Sampling simultaneously inside and outside the employees' abrasive blast hood has shown that the lower air concentrations inside the abrasive blast hood produce less overloading of the 37-mm cassettes [NIOSH 1998]; however, sampling inside PPE is not accepted by OSHA for compliance purposes [OSHA 2012a,b].

Aizenberg et al. [2000a] used a BAS with a prototype shield to evaluate PBZ exposures during abrasive blasting operations at four U.S. Air Force bases. The BAS (SKC Inc., Eighty Four, Pennsylvania) had a dome-shaped stainless steel screen sampling head with screen openings of a nominal diameter of 381 µm. The prototype shield was an additional external curved protective screen (4 × 2.5 inches). The reusable BAS had a collection efficiency that approximated the inhalable particle size-selective convention when operated at a flow rate of 4 Lpm [Aizenberg et al. 2000b]. The BAS was selected for the Air Force study because of its apparent durability and a screen design that was expected to prevent high-velocity abrasive particles from entering the sampler and damaging the filter. Although the unshielded BAS was developed to maintain sampling efficiency in the presence of wind currents that could cause the 37-mm cassette to underestimate inhalable aerosols [Kalatoor et al. 1995; Hauck et al. 1997; Aizenberg et al. 1998], the investigators found that the unshielded BAS was susceptible to particulate overloading. In response, the prototype shield was designed to protect the BAS from high-velocity abrasive materials, reduce clogging of the inlet screen, and prevent non-inhalable particles from overloading the filter. The investigators reported that the protective shield prevented non-inhalable particles from overloading the filter and did not interfere with sampling smaller particles; however, the researchers did not determine whether the prototype protective shield altered the collection efficiency of the BAS.

Following the U.S. Air Force study, SKC Inc. designed a snap-on dome-shaped stainless steel protective secondary shield for use with the BAS when sampling during abrasive blasting (Abrasive Blasting Sampler for Heavy Metals kit). This shield differed from the prototype screen tested previously by Aizenberg et al. [2000a]

in that the screen was circular and the screen openings were approximately 500 µm in diameter. The SKC shield was intended to protect the inlet screen from mechanical damage, prevent clogging, and exclude noninhalable particles while sampling during abrasive blasting operations. Although the collection efficiency of the unshielded BAS has been shown to approximate the international inhalability convention [Aizenberg et al. 2001], the collection efficiency of the commercially available shielded BAS has not been evaluated. Nevertheless, the shielded BAS is marketed as a sampler for abrasive blasting operations. Because of uncertainty about possible effects that shielding may have on the performance characteristics of the BAS, a goal of this HHE was to evaluate the effectiveness of this protective shield on the BAS in excluding noninhalable particulate.

Facility and Process Description

The shipyard used for this evaluation constructed naval and commercial vessels. Mild steel plates were fabricated into ship components called subsections. These subsections were welded together to build larger subassemblies, which were combined to form even larger units consisting of the hull, decks, bulkheads, tanks, and compartments. Each unit was moved into either a blast building or an outdoor blasting area for manual abrasive blasting to remove scale, rust, and lead-free preconstruction primer. Blasted units were then painted and joined to other units.

Employees performing abrasive blasting were provided with showers and separate lockers for street and work clothes. They were required by the shipyard to participate in a medical monitoring program that included physical examinations. Abrasive blasters wore gloves, boots, coveralls, and a Type CE airline respirator.

This evaluation was conducted outdoors in an area without mechanical ventilation. Coal slag abrasive was used. Unlike steel abrasives, coal slag shatters upon impact, creating smaller diameter particulate during abrasive blasting. We collected "active" and "passive" side-by-side PBZ samples outside the abrasive blasting hoods of randomly selected abrasive blasters. In this report "active" means that the air sampling device (the BAS or filter cassette) was connected to an air sampling pump, and "passive" means that these devices were not connected to an air sampling pump. The intent was to determine whether inertia-driven particulate entered the sampler.

Three rounds of air sampling were conducted, each for approximately 60 to 80 minutes coinciding with employees entering and exiting the blasting area. Because placing three sampling pumps on an abrasive blaster was impractical, we paired active samplers using three combinations: (1) shielded BAS and 37-mm cassette samplers, (2) unshielded and shielded BAS, and (3) unshielded BAS and 37-mm cassette samplers. Each employee was assigned a different pairing during each round of sampling.

Passive samples were collected by attaching a 4-inch length of Tygon tubing to the same type of sampler and filter used in active samples. Active and passive samples were located side-by-side, collecting up to 4 samples from each employee. A total of 11 active and 11 passive 37-mm cassette samples, 10 active and 2 passive unshielded BAS samples, and 12 active and 2 passive shielded BAS samples were collected in the three rounds. A limited number of passive BAS samples were collected because we had a limited number of BAS devices.

The cassettes and BAS samplers were visually examined at the laboratory and photographed to record evidence of particulate overloading, physical damage to either the filter or sampler, and clogged or damaged sampling screens. Exposure assessment of the abrasive blasters was not the focus of this evaluation. Therefore, the PBZ concentrations measured in this evaluation do not necessarily reflect the full-shift exposures to the abrasive blasters and are not comparable to occupational exposure limits for general industry and shipyards.

37-mm Cassette Sampling and Analysis

Active air samples were collected using precalibrated and postcalibrated AirChek® 52 air sampling pumps (SKC Inc., Eighty Four, Pennsylvania) at approximately 2 Lpm connected via Tygon® tubing to 37-mm cassettes containing a tared 37-mm diameter, 5-µm pore size, polyvinyl chloride filter.

Cassette samples were analyzed gravimetrically for total particulate according to NIOSH Method 0500 [NIOSH 2012]. Prior to gravimetric analyses, total particulate samples were separated into two fractions: (1) filter and particulate matter adhering to the filter, and (2) loose particulate matter. The loose particulates were removed from the cassette by turning the cassette upside down after the top was removed and collecting all particulate that fell freely from the cassette and/or filter. No tapping or other physical action was used. The two fractions were added to calculate the concentration of total particulate. The loose particulate fraction was visually compared with a Tyler Standard Screen Scale to determine the approximate particle size. The LOD was 0.02 mg/sample.

Button Aerosol Sampler Sampling and Analysis

Active samples were collected using precalibrated and postcalibrated AirChek® 224-PCXR8 sampling pumps (SKC Inc., Eighty Four, Pennsylvania) at approximately 4 Lpm attached to selected employees and connected, via Tygon tubing, to unshielded BASs (button aerosol sampler, part number 225-360, SKC Inc., Eighty Four, Pennsylvania) and shielded BASs (abrasive blasting sampler, part number 225-367, SKC Inc., Eighty Four, Pennsylvania) containing tared 25-mm diameter, 5-µm pore size, polyvinyl chloride filters.

BAS samples were gravimetrically analyzed for inhalable particulate according to NIOSH Method 0500 [NIOSH 2012]. Before analysis the filters were inspected for loose particles. Any loose particulate present was noted but not separated from the filter. The LOD was 0.02 mg/sample.

Results

Side-by-side air sample results for the three sampling methods are presented in Table 1. Although no samplers were lost or damaged, the air sampling pumps failed on two filter cassette samples, six unshielded BAS samples, and seven shielded BAS samples. The sampling time could not be estimated for some of the pump failures because the pump timers were not operating. Other sample failures included the air sampling pump shutting off or the airline tubing becoming disconnected between the filter cassette and pump during sampling. As a result of these sampling failures, we were left with only four pairs of side-by-side active samples to compare concentrations among different methods (bolded sampling results in Table 1).

Side-by-side active and passive unshielded BASs without a sampling failure resulted in only one valid sampling pair from Round 2, arco deck. The active sample collected 26 mg, while the passive sample collected 10 mg (sampling period of 69 minutes). No passive shielded BAS sample was collected with an active sample that did not experience a sampling failure. All BAS samples (active and passive) had loose particulate on the filters and the sampling devices, and the total weight of each sample exceeded the 2 mg recommended maximum sample loading for this method.

Gravimetric sampling results for paired active and passive 37-mm cassette samplers without sampling failure are presented in Table 2. The mass collected by the devices is reported so that active and passive samples can be easily compared. All but one passive 37-mm cassette sample exceeded the maximum weight of 2 mg per sample according to NIOSH Method 0500. For the 37-mm cassette active-passive pairs, the weight of some of the passive samples exceeded that of the corresponding active sample (Table 2). On average, passive 37-mm cassettes collected 74% of the mass compared to the corresponding active cassettes.

As shown in Table 2, loose particulate was found in the active and passive 37-mm cassettes. Most of this loose particulate was less than 53 µm in diameter (based on visual comparison with a Tyler Standard Screen Scale). One sample contained a few particles in the 297–420 µm range, and another contained a single particle in this range. The largest particle was in the 1190–1680 µm range. All but a few of the particles collected in these samples were within the inhalable size range of < 100 µm aerodynamic diameter.

Table 1. Side-by-side PBZ air sample results for the three active sampling methods

	Location	Total Time (min)	Concentration (mg/m³) 37-mm cassette	Unshielded BAS	Shielded BAS
Round 1	Open-air blasting on shaft covers	67	1,400*	—	580
	Beneath inverted Arco deck	76	—	70	†
	Unit 1230, large unit with piping	81	2,200	†	†
	Unit 1230, using man lift	61	1,500‡	—	25,000*
	Unit 1230, overhead blasting	NA§	—	†	†
Round 2	Arco deck	69	**43¶**	**90¶**	—
	Unit 1230	72	3,400**	—	†
	Unit 1230, using man lift	73	2,700††	2,400*	—
	unit 1230, using man lift	65	660‡‡	15§§	—
	Unit 1230, overhead blasting	72	610	—	†
	Arco deck, open area	47	—	**480¶**	**160¶**
Round 3	Arco deck	75	—	**280¶**	**75¶**
	Unit 1230	27	—	79*	200*
	Unit 1230, using man lift	68	930	†	—
	Unit 1230, overhead blasting	40	**110¶**	—	**150¶**
	Arco deck, open area	87	†	—	84
Total percent of sample failure			18%	60%	58%

*Sampling pump faulted and active sampling period was known, but less than the entire sampling period.
†Sampling pump faulted and active sampling period was unknown, but less than the entire sampling period.
‡When the sampler was opened, the filter was stained, wrinkled, and off center.
§NA = not available.
¶ Bolded numbers are sample pairs that had no sampling failures and can be compared.
**The approximate size of few loose particles was 297–420 µm.
††The approximate size of one loose particle was 1190–1680 µm.
‡‡The approximate size of one loose particle was 297–420 µm.
§§Sampling pump inadvertently switched off.

Table 2. Side-by-side PBZ active and passive 37-mm cassette air sample results without a sampling failure*

Round	Location	Total Time (min)	Active 37-mm Cassettes Mass (mg) Total Dust	Active Loose Particle	Active % Loose Particle	Passive 37-mm Cassettes Mass (mg) Total Dust	Passive Loose Particle	Passive % Loose Particle
Round 1	Unit 1230, large unit with piping	81	330	330	99†	370	370	100
	Unit 1230, using man lift	61	180‡	170	97	110	110	97†
Round 2	Arco deck	69	5.6	1.9	34	ND§	ND	ND
	Unit 1230	72	470¶	460	99	140	140	98†
	Unit 1230, using man lift	73	380**	380	99†	290	290	99†
	Unit 1230, using man lift	65	85††	78	92	17	16	96
	Unit 1230, overhead blasting	72	85	79	93	28	28	99†
Round 3	Unit 1230, using man lift	68	130	120	96	220	220	99†

*Data are shown to two significant digits.
†Data less than 100% because of the rounding to two significant digits.
‡When the sampler was opened, the filter was stained, wrinkled, and off center.
§ND = not detected, the mass was below the LOD.
¶The approximate size of few loose particles was 297–420 µm.
**The approximate size of one loose particle was 1190–1680 µm.
††The approximate size of one loose particle was 297–420 µm.

As shown in Figure 1, the shielded BASs overloaded despite the protective shield. The shielded BAS shown in Figure 1 was connected to a pump that faulted 10 minutes into the 61-minute sampling period. Figure 2 shows a 37-mm cassette sample whose pump operated for the entire 61-minute sampling period. Both samples in Figure 1 and 2 were grossly overloaded, well beyond the recommended maximum sample weight of 2 mg per sample.

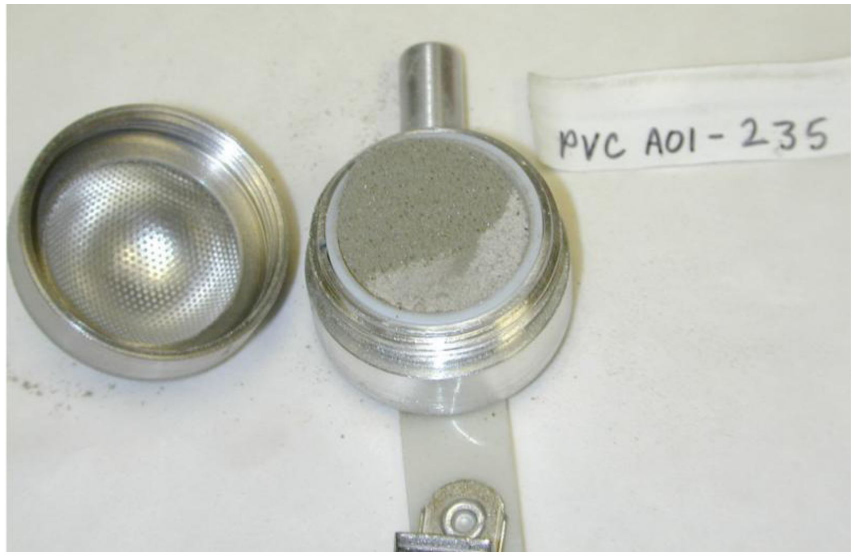

Figure 1. Loose particulate inside a shielded BAS active sample. The external shield that would go over the protective screen is not shown.

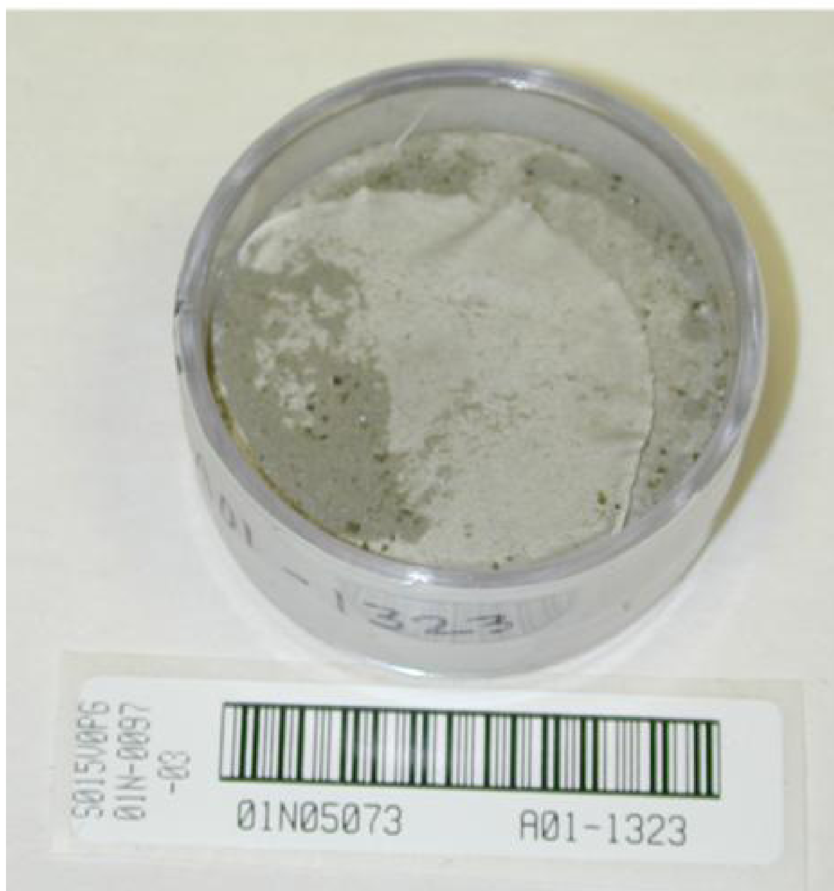

Figure 2. Loose particulate and a damaged filter from a 37-mm filter cassette active sample.

Discussion

The first objective of this evaluation was to compare three commercially available abrasive blasting sampling devices. Because of sampling failures, fewer than half of the BAS samples produced reliable gravimetric data. Overloading likely caused high back pressures resulting in failure of the sampling pumps. The harsh abrasive blasting environment also contributed to sample failures by disconnecting tubing or unintentionally turning off pumps. As a result, very few paired samples were available to compare 37-mm cassette results with shielded and unshielded BAS results. Among paired samples, overloading was a problem with most 37-mm cassettes and all BAS samples. Overloading of 37-mm cassettes was further verified by the loose particulate inside the sampler that could not adhere to the filter. Although a statistical comparison of sampler performance was not possible because of insufficient data, we made general observations regarding the usability of these samplers during abrasive blasting.

The presence of loose particulate in the 37-mm cassettes and the overloaded samples was not surprising because both have been documented during abrasive blasting operations using steel shot [NIOSH 1994, 1998] and coal slag [NIOSH 2007]. Noninhalable particulate of steel grit trapped in the cassette has also been documented [NIOSH 1994; OSHA 2012a]. In this evaluation, the presence of a few large loose particulates inside the 37-mm cassettes verifies that noninhalable particulate can enter into the sampler during abrasive blasting using coal slag. In contrast, overloading and the presence of loose particulate in the BASs were unexpected because the outer shield was designed to prevent this occurrence [SKC 2012].

The second objective was to evaluate whether the shielded BAS prevented inertia-driven particles from overloading the sampler. Inertia-driven particulate entering passively accumulated in all unshielded and shielded BASs as well as most of the 37-mm cassettes. The BAS also presented analytical challenges because particulate was found in the grooves of the protective screen, behind the filter backup pad, and stuck to the sample label. The presence of loose particulate in the BAS was not anticipated and in retrospect should have been handled similarly to the loose particulate in the 37-mm cassette samples (separated into two fractions and size of loose particulates measured). Therefore, we cannot estimate the percentage of loose particulate in the BAS or if there was non-inhalable particulates in the loose portion.

Discussion (continued)

It is difficult to estimate the true PBZ concentration for the 37-mm cassette samples because of the considerable inertia-driven particulate that was collected (Table 2). The passive accumulation for the 37-mm cassettes was variable and unpredictable, thus preventing us from developing correction factors that could be used to adjust for the passive loading captured by the active samples. At the time of this evaluation there was no method to prevent this inertia-driven particulate from entering the 37-mm cassette samplers (either actively or passively) without adversely affecting collection efficiency and/or the reliability of aerosol samplers in abrasive blasting environments.

The external protective shield developed and sold by the manufacturer of the BAS has not been thoroughly evaluated in abrasive blasting environments to determine its effect on collection efficiency. Even if the accuracy and precision of results obtained using shielded BASs could be determined under abrasive blasting conditions, overloading may continue to be a problem. Shortening the sampling period by removing the sampling device may reduce or prevent overloading but may be impractical in the shipyard environment because it could disrupt the abrasive blasting operation. Alternatively, leaving the sampling device in place but shutting off the sampling pump (via a pump timer) may not prevent overloading because inertia-driven particulate could still passively enter the sampling device. Stephenson et al. [2002] reported copper slag abrasive generating total particulate aerosols that exceeded the OSHA permissible exposure limit within 15 minutes of blasting under controlled conditions. Considering that most abrasive blasting operations are longer than 15 minutes, alternative methods for accurately and reliably measuring air concentrations during abrasive blasting environments are warranted.

Conclusions

NIOSH evaluated three air sampling methods during outdoor abrasive blasting using coal slag. We found that the three sampling methods resulted in overloaded samples, which caused frequent sampling pump failures. The 37-mm cassettes collected large noninhalable particulate and presented overloading problems. Even though known challenges remain with the 37-mm cassettes, neither the unshielded or shielded BASs appear to be viable alternatives to the 37-mm cassettes to accurately assess exposures in abrasive blasting environments.

Conclusions (continued)

Current PBZ air sampling techniques do not accurately represent employee exposures during abrasive blasting. All three sampling methods were likely to overestimate air concentrations. Therefore, sampling methods that can more accurately estimate exposures during abrasive blasting operations are needed. We are not aware of any PBZ sampling methods that are suitable to accurately measure exposures during abrasive blasting outside the blasting hood. Identification of alternative methods for sampling during abrasive blasting operations is still warranted.

Data were not available to assess the influence of the secondary protective shield on the shielded BAS performance to collect inhalable particulate. Further assessment of the effectiveness of the shielded BAS for the PBZ sampling during abrasive blasting operations is needed. Identification of an alternative barrier or shield that can prevent loose or inertia-driven particulate from entering samplers without affecting collection accuracy and precision is warranted.

References

Aizenberg V, Bidinger E, Grinshpun SA, Willeke K, Hamed A, Tabakoff W [1998]. Airflow and particle velocities near a personal aerosol sampler with a curved, porous aerosol sampling surface. Aerosol Sci Technol *28*(3):247–258.

Aizenberg B, England A, Grinshpun S, Willeke K, Carlton G. [2000a]. Metal exposures among abrasive blasting workers at four U.S. air force facilities. Appl Occup Environ Hyg *15*(10):766–772.

Aizenberg V, Grinshpun SA, Willeke K, Smith J, Baron P [2000b]. Performance characteristics of the button personal inhalable aerosol sampler. AIHAJ *61*(3):398–404.

Aizenberg V, Choea, K, Grinshpun SA, Willeke K, Baron P [2001]. Evaluation of personal aerosol samplers challenged with large particles. J Aerosol Sci *32*(6):779–793.

Clayton GD, Clayton FE [1978]. Patty's industrial hygiene and toxicology. Vol I: general principles, 3rd rev. ed. New York: John Wiley & Sons.

References (continued)

Hauck B, Grinshpun S, Reponen A, Willeke K, Bornschein R [1997]. Field testing of new aerosol sampling method with a porous curved surface as inlet. AIHAJ *58*(10):713–719.

Kalatoor, S. Grinshpun S, Willeke K, Baron P [1995]. New aerosol sampler with low wind sensitivity and good filter collection uniformity. Atmos Environ *29*(10):1105–1112.

NIOSH [1987]. Guide to industrial respiratory protection. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 87-116.

NIOSH [1994]. Health hazard evaluation and technical assistance report: Bath Iron Works Corporation. By D. Sylvain. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA Report No. 94-0122-2578.

NIOSH [1998]. Health hazard evaluation and technical assistance report: Avondale Shipyards. By M. Kiefer, D. Trout, M. E. Wallace. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA Report No. 97-0260-2716.

NIOSH [2007]. Applied research and technology report: Control technology and exposure assessment for occupational exposure to beryllium: Abrasive blasting with coal-slag. By K. G. Crouch, A. S. Echt, R. Kurimo, Y. T. Gagnon. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH DART Report No. EPHB 263-13a.

NIOSH [2012]. NIOSH manual of analytical methods, 4th ed. Schlecht PC, O'Connor PF, eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 94–113 August, 1994); 1st Supplement Publication 96135, 2nd Supplement Publication 98–119; 3rd Supplement 2003–154. [http://www.cdc.gov/niosh/nmam/]. Date accessed: June 2012.

OSHA [2012a]. Abrasive blasting monitoring requirements and sampling procedures. Standard interpretation of August 13, 1999, from Richard E. Fairfax, Director Directorate of Compliance Programs. Occupational Safety and Health Administration, to Irene S. Fanelli, Environmental Health Consultants. [http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=22777]. Date accessed: June 2012.

OSHA [2012b]. U.S. Department of Labor Occupational Safety and Health Administration. Directorate of Standards and Guidance. Office of Maritime. An OSHA guidance document. December 2006. [http://www.osha.gov/dts/maritime/standards/guidance/shipyard_guidance.html]. Date accessed: June 2012.

SKC [2012]. Abrasive Blasting Sampler 225-367 Product Data Bulleting. Publication 1602 Rev 1102. [http://www.skcinc.com/instructions/1602.pdf]. Date accessed: June 2012.

Stephenson D, Spear T, Seymour M, Cashell L [2002]. Airborne exposure to heavy metals and total particulate during abrasive blasting using copper slag abrasive. Appl Occup Environ Hyg *17*(6):437–443.

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Acknowledgments and Availability of Report

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found. HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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