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Evaluation of Air Sampling Methods for Abrasive Blasting

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Introduction

The National Institute for Occupational Safety and Health (NIOSH) investigators compared methods for collecting personal breathing zone (PBZ) air samples for particulates during abrasive blasting at a shipyard. Abrasive blasting is the cleaning or finishing of surfaces by the use of an abrasive carried in a strong current of air. The U.S. government has provided regulatory requirements and guidelines for ventilation, enclosures, and personal protective equipment during abrasive blasting [NIOSH 1987; OSHA 2012a]. However, current Occupational Safety and Health Administration (OSHA) sampling and analytical methods can overestimate worker exposures to airborne metals and other particulate contaminants during abrasive blasting [NIOSH 1994; NIOSH 1998; OSHA 2012b].

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, have been proposed as alternatives to assess exposure. All were found to be impractical or ineffective 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. [2000] used a Button Aerosol Sampler® (BAS) (part number 225–360, SKC Inc., Eighty Four, Pennsylvania) with a prototype shield to evaluate PBZ exposures during abrasive blasting operations. 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 Aizenberg et al. [2000] 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, part number 225–367, SKC Inc., Eighty

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Four, Pennsylvania). This shield differed in size, shape, and screen opening from the prototype screen tested by Aizenberg et al. [2000]. Due to uncertainty about possible effects that shielding may have on the performance characteristics of the BAS, the objectives of this evaluation were to: (1) compare the commercially available BAS (with and without the shield) with the conventional 37-mm cassette sampler in an abrasive blasting environment and (2) evaluate whether the protective shield designed for the BAS prevented inertia-driven particles from entering and possibly overloading the sampler [NIOSH 2012a].

Observations

The shipyard where this work was conducted 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. An abrasive blaster at this shipyard wore gloves, boots, coveralls, and a Type CE airline respirator (Figure 1).

Assessment

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 BASs and 37-mm cassette samplers, (2) unshielded and shielded BASs, and (3) unshielded BASs 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 four samples from each employee. A total of 11 active and 11 passive 37-mm cassette samplers, 10 active and 2 passive unshielded BASs, and 12 active and 2 passive shielded BASs 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 cassette 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. Although exposure assessment was not conducted, employees did not alter their work during this evaluation and therefore our sampling is representative of the industry practices.

37-mm Cassette Sampling and Analysis

Active air samples were collected using pre- and post-calibrated AirChek® 52 air sampling pumps (SKC Inc., Eighty Four, Pennsylvania) at approximately 2 liters per meter (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 2012b]. 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 limit of detection (LOD) was 0.02 mg/sample.

Button Aerosol Sampler Sampling and Analysis

Active samples were collected using pre- and post-calibrated 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 and shielded BASs 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 2012b]. 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. 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 BAS without a sampling failure resulted in only one valid sampling pair from Round 2 at the arco deck (data not shown in tables). 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 NIOSH Method 0500, despite relatively short sampling times.

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 recommended 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.

As shown in Figure 2, the shielded BASs overloaded despite the protective shield. The shielded BAS shown in Figure 2 was connected to a pump that faulted 10 minutes into the 61-minute sampling period. Figure 3 shows a 37-mm cassette sample whose pump operated for the entire 61-minute sampling period. Both samples in Figure 2 and 3 were grossly overloaded, well beyond the recommended maximum sample weight of 2 mg per sample.

Discussion

The first objective of this evaluation was to compare the performance of shielded and unshielded BASs with that of conventional 37-mm cassette sampler in a shipyard abrasive blasting environment. 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 from disconnected tubing or pump faults. 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 2012b]. In this evaluation, the presence of large loose particulate inside the 37-mm cassettes verifies that noninhalable particulate can enter 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 passively accumulated in all unshielded and shielded BASs as well as most of the 37-mm cassettes. The BASs 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 BASs, nor can we assess whether there was non-inhalable particulates in the loose portion.

It is not possible 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 of particulates in 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 in the active samples. At the time of this evaluation there was no recognized 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 can still passively enter the sampling device. Stephenson et al. [2002] reported that abrasive blasting using copper slag generated total particulate aerosols that exceeded the OSHA permissible exposure limit within 15 minutes of blasting under controlled conditions. Considering that many 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 investigators 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 BAS appear to be viable alternatives to the 37-mm cassettes to accurately assess exposures in abrasive blasting environments. Assessment of the effectiveness of the shielded BAS or 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.

Current PBZ air sampling techniques are not effective in assessing employee exposures during abrasive blasting. 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 assessing worker exposure during abrasive blasting operations is still needed.

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Figure 1.
Employee performing abrasive blasting of the surface of a shaft cover. Employee is wearing gloves, boots, coveralls, a Type CE airline respirator, and two sampling pumps.

Figure 2.
Loose particulate inside a shielded BAS active sample. The external shield that would go over the protective screen is not shown.

Figure 3.
Loose particulate and a damaged filter from a 37-mm filter cassette active sample.

Table 1

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

	Location	Total Time (min)	Concentration (mg/m^3)		
			37-mm cassette	Unshielded BAS	Shielded BAS
Round 1	Open-air blasting on shaft covers	67	1400*	—	580
	Beneath inverted Arco deck	76	—	70	†
	Unit 1230, large unit with piping	81	2200	†	†
	Unit 1230, using man lift	61	1500‡	—	25000*
	Unit 1230, overhead blasting	NA	—	†	†
Round 2	Arco deck	69	**43** ¶	**90** ¶	—
	Unit 1230	72	3400**	—	†
	Unit 1230, using man lift	73	2700††	2400*	—
	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*

	Location	Total Time (min)	Active 37-mm Cassettes Mass (mg)			Passive 37-mm Cassettes Mass (mg)		
			Total Dust	Loose Particle	% Loose Particle	Total Dust	Loose Particle	% 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 1	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.