CPWR TECHNICAL REPORT

Field Tests of a Water Induction Nozzle as a Dust Control for Abrasive Blasting

January 2007

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This research was made possible by The Center to Protect Workers' Rights (CPWR) as part of a cooperative agreement with the National Institute for Occupational Safety and Health, NIOSH (NIOSH grant OH008307). The research is solely the responsibility of the author and does not necessarily represent the official views of NIOSH. CPWR—a research, development, and training arm of the Building and Construction Trades Department, AFL-CIO—is uniquely situated to serve workers, contractors, and the scientific community. A major CPWR activity is to improve safety and health in the U.S. construction industry. CPWR, Suite 1000, 8484 Georgia Ave., Silver Spring, MD 20910, 301-578-8500, www.cpwr.com.

Acknowledgements

This project was supported with a grant from The Center to Protect Workers' Rights (CPWR). The gracious hospitality and support of Judy and Kevin Jewell during this project are sincerely appreciated. The generous cooperation and assistance of the workers at this site are invaluable.

Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
GM	geometric mean
GSD	geometric standard deviation
lpm	liters per minute
mg/m^3	milligrams per cubic meter
$\mu g/m^3$	micrograms per cubic meter
NIOSH	National Institute for Occupational Safety and Health
OSHA	U.S. Occupational Safety and Health Administration
PEL	permissible exposure limit (OSHA)
REL	recommended exposure limit (NIOSH)
TLV	threshold limit value (ACGIH)
WIN	water induction nozzle

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Abstract

Field tests of a wet abrasive blasting device resulted in significantly lower respirable crystalline silica dust levels than comparable exposure data reported in the literature. The tested device was the water induction nozzle (WIN) (Boride Products), a venturi nozzle in which water is added to the abrasive-air mixture to suppress dust during abrasive blasting. Workers were monitored for silica exposure while performing abrasive blasting on precast concrete, using the WIN and abrasive sand from which the fines had been removed. The monitoring was conducted at Olympian Precast in Redmond, Washington, over a five-day period in September 2006. The geometric mean respirable dust and respirable crystalline silica exposure levels were, respectively, 0.5 and 0.06 mg/m^3. These levels are lower by a factor of 7 (for respirable dust) and 4 (for respirable crystalline silica) than exposure data recently reported for construction workers performing dry abrasive blasting. Controlled laboratory testing is needed to quantify the effectiveness of the WIN nozzle in suppressing dust, separate from the dust control provided by the use of abrasive sand with fines removed. Research is also needed to determine recommended water application rates.

Introduction

Abrasive blasting with sand produces extremely high respirable crystalline silica levels and puts workers at severe risk of developing silicosis [NIOSH 1992a, 1996, 1998]. The National Institute for Occupational Safety and Health (NIOSH) has estimated that 100,000 workers are exposed to respirable crystalline silica during abrasive blasting [Migliozzi and Gromen 1997]. Despite ongoing efforts to increase awareness about the hazards of silica and to reduce workplace exposure, workers performing abrasive blasting continue to be exposed to high levels of silica. Two studies summarizing recent silica exposure data reported geometric means of 0.24 milligrams per cubic meter (mg/m^3) [Flanagan et al. 2006] and 1.48 mg/m^3 for respirable crystalline silica [Rappaport et al. 2003], measured during abrasive blasting operations in the construction industry (Table 1). These levels are significantly higher than the NIOSH recommended exposure limit (REL) of 0.05 mg/m^3 for respirable crystalline silica [NIOSH 2002].

Table 1. Recent data compilations of crystalline silica exposure levels during abrasive blasting in construction

Reference	Substance	Geometric mean (mg/m^3)	Geometric standard deviation	Number of samples
Flanagan et al. 2006	respirable crystalline silica	0.24	5	64
	respirable dust	3.74	5.9	65
Rappaport et al. 2003	respirable crystalline silica	1.48	5.09	14
	respirable dust	14.15	4.00	14

Recent efforts have focused on the use of non-silica abrasives as a way to reduce silica exposure. But eliminating sand as the abrasive does not always eliminate excessive exposure to respirable crystalline silica. For instance, high silica exposures can result when workers perform abrasive blasting on materials such as concrete surfaces or surfaces coated with silica-containing paint, even when using non-silica abrasives. The paint on some metal surfaces can be a source of crystalline silica exposure when coal slag is used for abrasive blasting [CPWR 2004]. A study by Meeker et al. [2005] found that when specular hematite was used to perform abrasive blasting on a steel structure coated with a crystalline silica–containing paint, geometric mean respirable dust and respirable crystalline levels were, respectively, 237 and 2.7 mg/m^3. In this case, the crystalline silica exposure was attributed to the paint, as the abrasive did not contain crystalline silica.

Wet blasting methods present another means of reducing silica exposure during abrasive blasting. The main commercially available wet methods are described in the section below. To date, the effectiveness of these methods in controlling exposure to hazardous dust has not been widely studied.

Study Objective

The purpose of this study was to evaluate the effectiveness of using a wet abrasive blasting device, the water induction nozzle (WIN), to control worker exposure to respirable crystalline silica. The study was conducted at Olympian Precast in Redmond, Washington, in September 2006. The WIN nozzle, manufactured by Boride Products (Traverse City, Michigan), mixes abrasive with water. The addition of water is intended to suppress dust generated by both the abrasive and the surface being abraded. Olympian Precast uses wet abrasive blasting to obtain the desired appearance of architectural concrete castings. At the Olympian Precast plant, the wet abrasive blasting is done outdoors in a manner that is very similar to the abrasive blasting operations typical of the construction industry. Thus, the study results may be applicable to construction workers performing abrasive blasting on concrete.

Overview of Wet Blasting Technology

A review of the commercial literature identified five main methods that use water to suppress dust generation during abrasive blasting: water ring, water induction nozzle, water injection, wet abrasive blasting, and jet blasting.

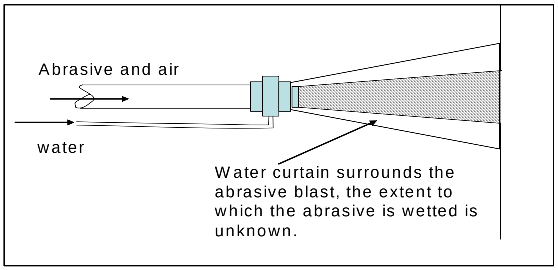

Figure 1. Schematic illustration of water ring attachment for an abrasive blasting nozzle. These nozzles cost less than $100.

Water ring: The water ring (Figure 1) is an annular-shaped fitting placed on the end of an abrasive blasting nozzle [Neulicht and Shular 1997]. Pressurized water is forced through the fitting and the abrasive flows through the annular space surrounded by water. The water application rate is not controlled and workers simply adjust the amount of water used to eliminate visual dust. This method of dust control is thought to be 50-85% efficient, but the relation between water flow rate and dust emissions has not been studied for this device [Neulicht and Shular 1997]. These devices cost less than $100.

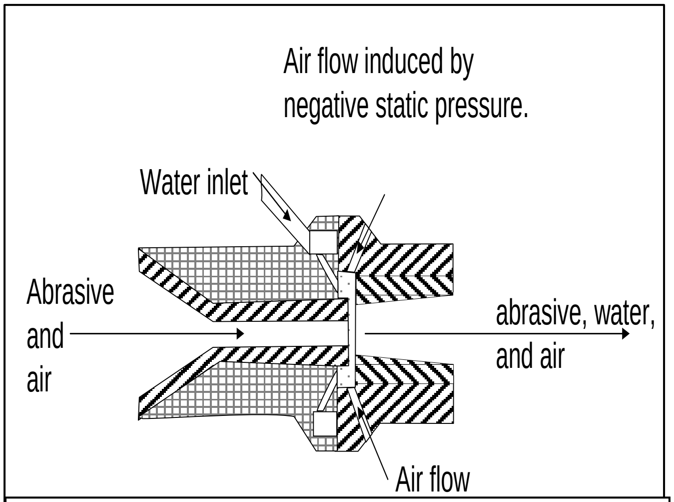

Figure 2. Cross-sectional illustration of water induction nozzle (WIN). The intent is to mix water with the flowing abrasive and air. Water can be supplied from a garden hose at pressures as low as 20 psig. These nozzles are sold for less than $500.

Water induction nozzle: As shown in Figure 2, the water induction nozzle (WIN) (Boride Products, Traverse City, Michigan) draws water into the abrasive and mixes the water with the abrasive-air mixture, which results in the atomization of the liquid droplets that are incorporated into the abrasive blasting stream [Gardner and Gulau 1991]. As these droplets accelerate, they collide with solid particles, perhaps resulting in liquid-coated particles. This nozzle costs about $500 and reportedly eliminates visible dust emissions. The patent reported that visual dust was reduced as water flow rate increased from 1 to 5 liters per minute.

Material feed rates were not disclosed in the patent application [Gardner and Gulau 1991]. The patent document did not report quantitative measurement of emission reduction.

Water injection: Clemco Industries (Washington, Missouri) produces the Clemco Wetblast Injector System, a system for pumping water into the air-abrasive mixture produced by an abrasive blasting pot (schematically illustrated in Figure 3) [Clemco Industries 1998]. Compressed air is used to drive a pump that forces the water through jets that inject the water into the air-abrasive mixture. The water can be supplied by a household tap or a tank. This system avoids the use of electric pumps, thereby eliminating the risk of electrical shock. The water flow can be varied between 0 and 3 liters per minute. The cost for this unit is $2100, and its ability to suppress dust emissions has not been reported.

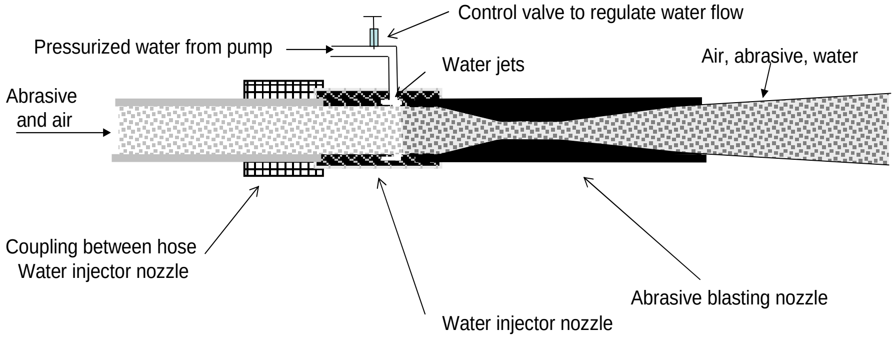

Figure 3. Schematic illustration of the Clemco Industries water injector systems, marketed as the **Clemco Wetblast Injector System**. A compressed air pump forces water through atomizing jets that create a mist. The abrasive blasting nozzle has a venturi shape that may enhance contact between the water and abrasive particles.

Ultra high-pressure water jet system: Jet Edge (St. Michael, Minnesota) manufactures and markets a high-pressure surface-cleaning system that is used for the same purposes as wet abrasive blasting [Jet Edge undated]. This system uses water at a rate of 7 liters per minute with a pressure of 3800 bar (55,000 pounds per square inch). To develop this pressure, the water flows through a piston pump that reportedly compresses the water. A lance is used to apply this high-pressure water to clean steel structures or to remove deteriorated concrete from concrete structures. A walk-behind applicator is used to clean flat surfaces, such as steel decks and paved concrete decks of parking lots. Perhaps this greatly reduces exposures. In addition, it has provisions for introducing abrasives such as garnet or metal slags.

In the Aquablast System, by Jet Edge, abrasives are sometimes added to the high-pressure water. Ultra high-pressure water blasting cannot produce a profile on a metal surface. To achieve a profile, the abrasive materials, with a density larger than 4 grams per cubic centimeter (g/cm^3) are added to the water. The abrasive roughens the surface, enhancing paint adhesion. This type of wet blasting eliminates the need to build enclosures around structures. Abrasive consumption rates are typically 0.4-1.4 kilograms per minute for garnet, and the water application rate can be as high as 12 liters per minute. This equipment is expensive compared with several other wet methods. The deck blaster, shown in Figure 4, costs about $25,000 and the ultra high-pressure pump costs $135,000. The company makes this equipment available for lease.

Figure 4. Ultra high-pressure water is used to clean concrete surface on a parking ramp. (Photograph courtesy Jet Edge). Apparently the use of water greatly suppresses the dust generation.

Torbo Wet Abrasive Blasting Systems®: Known commercially as Torbo Blasting (Kreizer Technologies, Euless, Texas), this system mixes water and abrasive in a pressurized tank, at a ratio of about 80% abrasive and 20% water. The wet abrasive is fed by a metering valve into the compressed air that transports the abrasive to the blasting nozzle. In this process, the individual abrasive particle is coated with water. The water suppresses the dust generated from the abrasive and, to some extent, from the abraded substrate. The cost for the Torbo Blasting system varies between $10,000 and $30,000.

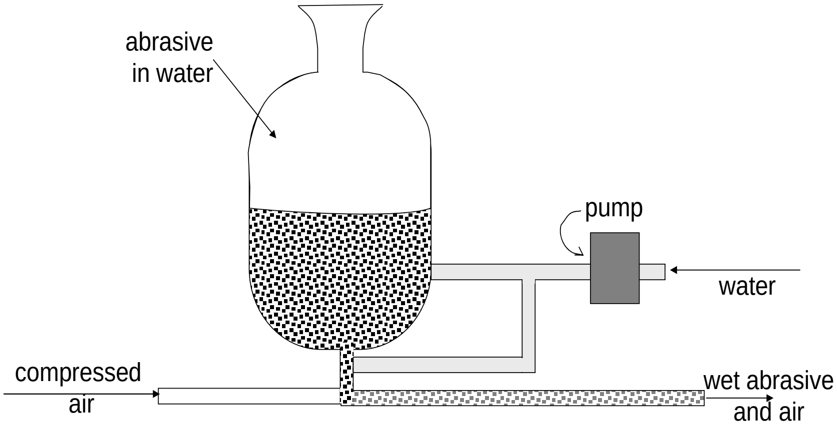

Figure 5. Schematic illustration of Torbo Blasting system.

Dust exposures during Torbo blasting appear to reduce lead exposures during abrasive blasting of structures coated with lead paint. When this system was used to remove lead-containing paint from two test houses, average blaster lead exposures were reported to be between 55 and 81 micrograms per cubic meter (µg/m^3) [Daniels et al. 2001]. For blasting a steel structure with nickel slag and silica sand, dry blasting resulted in lead levels of 1130 and 774 µg/m^3. In contrast, wet abrasive blasting resulted in lead levels of 45 and 46 µg/m^3 [Gustafson and Hock 1997]. The lead exposure was generated by pulverizing the paint on the surface being cleaned, and wet abrasive blasting apparently reduces the amount of dust generated by pulverizing the paint. In another case study of Torbo blasting, sand (nearly 100% crystalline silica) was used to perform abrasive blasting on a concrete structure. The geometric mean respirable dust and respirable crystalline silica exposures were, respectively, 1 and 0.2 mg/m^3 for workers on an elevated platform [Heitbrink 1999; Golla and Heitbrink 2004]. Thus, the available literature suggests that this form of wet abrasive blasting can reduce silica exposure by a factor of 3 to 20, depending on the conditions.

Exposure Evaluation Criteria

Occupational exposure limits are used to judge the acceptability of worker exposure to hazardous substances. The exposure limits relevant in this study are those developed for respirable dust, respirable crystalline silica, and inhalable dust. *Respirable dust* refers to the dust particle size that can penetrate to the very deepest parts of lungs, where the transfer of oxygen and carbon dioxide occurs. Inhalable dust can be deposited anywhere in the respiratory system. The American Conference of Governmental Industrial Hygienists (ACGIH) has published size-selective criteria for these dusts [ACGIH 2006a]. Exposure evaluation criteria are available from the Occupational Safety and Health Administration (OSHA), NIOSH, and ACGIH. Exposure limits developed by these groups are summarized in Table 2. These limits are based on full-shift time-weighted-average (TWA) samples obtained in the worker's breathing zone.

Table 2. Exposure evaluation criteria

Source of occupational exposure limit	**Respirable dust (mg/m^3)**	**Respirable crystalline silica (mg/m^3)**	**Inhalable dust (mg/m^3)**
OSHA Permissible Exposure Limits (PEL)	5	$\frac{10\ \text{mg/m}^3}{(\%SiO_2+2)}$ See note b	15
NIOSH Recommended Exposure Limits (REL)		0.05	
ACGIH Threshold Limit Values (TLV)[a]	3	0.025	10

[a] Although ACGIH has withdrawn the TLVs for respirable and inhalable dust, ACGIH continues to recommend that dust exposures be kept below these specified values, noting that even relatively inert materials may have adverse health effects at high exposure levels.

[b] The OSHA PEL for crystalline silica is an exposure limit on the respirable dust concentration that varies with the percentage of crystalline silica in the respirable dust. This PEL is approximately 0.1 mg/m^3 of respirable crystalline silica, twice the comparable NIOSH REL.

The OSHA PELs are legally enforceable occupational exposure limits. Many OSHA PELs are somewhat dated and may be based on considerations of both technological feasibility and health effects. The current OSHA PEL for crystalline silica was published as an ACGIH TLV in 1972 [ACGIH 2006b]. NIOSH RELs are based on reported health effects. The NIOSH REL for crystalline silica is intended to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002].

The ACGIH TLV for crystalline silica is intended to prevent pulmonary fibrosis (silicosis) and lung cancer. Workers exposed to concentrations in excess of 0.065 mg/m^3 of respirable quartz reportedly experience a significant increase in lung cancer mortality [Steenland and Sanderson 2001]. ACGIH noted, “Graham et al. found that when retirees whose workplace silica-exposure concentrations averaged 0.06 mg/m^3 were studied, the risk of silicosis was significantly greater (7.1% versus 1.2%) when compared to employees examined at or before retirement” [Graham et al. 2004; ACGIH 2006b]. ACGIH recommends that respirable crystalline silica exposures be kept below 0.025 mg/m^3 so that workers will not have developed silicosis by the time they reach retirement age [ACGIH 2006a]. ACGIH is a private scientific association whose TLVs are intended to be exposure levels that typical workers can experience without adverse health outcomes. ACGIH’s recommendations do not involve considerations of technological feasibility and the group emphasizes that TLVs should not be interpreted as fine lines between safe and unsafe working conditions.

Methods

The goals of the research were to:

- Assess workers’ exposure to respirable crystalline silica, respirable dust, and inhalable dust during wet abrasive blasting on precast concrete with the WIN nozzle.
- Assess how work practices might affect dust exposure, using video exposure monitoring to depict workers’ activities, while concurrently measuring dust levels with a real-time monitor.

Study Site

The study was conducted at a manufacturer of architectural precast concrete, Olympian Precast, located in Redmond, Washington, from September 5 to 11, 2006. At this facility, abrasive blasting is performed to achieve the desired surface texture on custom structural products. Abrasive blasting is performed outdoors in a manner that is similar to abrasive blasting work in construction. The work is also similar to construction work in that the facility produces custom products as specified by contractor demand. As in construction, the amount of abrasive blasting varies from day to day. Wet abrasive blasting is performed at this facility to achieve the desired appearance per specifications provided by the customer. Sometimes abrasive blasting is done to expose the underlying aggregate. At other times, it is done to roughen a surface to reduce slipping hazards or to even the color distribution.

Typically, two or three workers perform abrasive blasting at three different work stations located out of doors (Table 3): large station, small station, and Crane Way station. The following sections describe the work performed at each station during the five days of exposure monitoring:

Large station: Building panels were set about one foot above the ground (Figure 6). The worker performed abrasive blasting to expose the underlying aggregate. As shown in Figure 7, the surface of the finished product has a rough texture and the underlying aggregate is visible. The number of panels treated each day varied. This station was located on the western side of the property, away from other operations.

Small station: The worker performed abrasive blasting on two building fire exit stairs each day (Figure 8). The stairs were set on blocks about one foot above the ground. The abrasive blasting was done to roughen the surface and the underlying aggregate was occasionally visible. The fire exit stairs had platforms that were 46 by 44 inches at the bottom and 34 by 46 inches at top. Each of the ten stair steps had a dimension of 12 by 44 inches. This station was located in the middle of the property, approximately 50 feet west of the main building.

Crane Way station: Relatively large panels were treated here (Figure 9). These panels, 80 inches high and 345 inches long, were positioned vertically. During the five days of exposure monitoring at this station, two of these panels were treated each day. The abrasive blasting on these panels was intended to give the panels a more even color. The surface was barely roughened. This station was located on the east side of the property, slightly north of the main production building and adjacent to the road.

The sand used in all of the abrasive blasting operations was obtained from Manufacturers Mineral in Renton, Washington. The sand, reportedly 59% crystalline silica, is treated to remove the fines. The purchase specification on the sand limits the fines content (sand passing through a 100-mesh screen) to less than 3% by weight prior to use. The sand is supplied to the abrasive blasting pot from overhanging bins (Figures 8 and 10). The abrasive blasting pots are filled every 20 to 40 minutes. To fill the pots, the worker opens a valve and sand flows into the pot. This procedure creates a visible dust plume (Figure 10). The workers were generally able to stand clear of this plume when filling the abrasive blasting pot.

Figure 6. At the large station, building panels are placed on blocks about 1 to 2 feet above the ground. The worker stands on the ground or on the object to perform abrasive blasting. At regular intervals, the worker rinses off the object with water to determine whether the correct finish is being obtained. During the study, the worker was exposing some of the underlying aggregate. Note that this wet abrasive blasting process inevitably generates mud and water puddles as depicted. However, the process and work practices suppress the resuspension of dry sand.

Figure 7. Exposed aggregate after blasting building panels at the large station. The underlying aggregate is clearly visible and the surface appears to have been roughened.

Figure 8. At the small station, the worker performs wet abrasive blasting on fire exit stairs. The bin for filling the abrasive blasting pot is in the background on the left. The aggregate is barely visible.

Figure 9. A worker performs wet abrasive blasting on a wall panel at the Crane Way station. The goal was to obtain a uniform color, and only a minimal amount of material was removed. The object thickness was not appreciably reduced. Note that the water drains from the product and the used sand is kept wet.

Figure 10. Filling the abrasive blasting pot with dry sand creates obvious dust emissions. The sand flows by gravity through a chute into the abrasive blasting pot. The workers are generally able to avoid the dust plume. The purchase specification on the sand limits the fines content (sand passing through a 100-mesh screen) to less than 3% by weight.

Documentation of Test Conditions

The airborne exposures of workers are known to vary with environmental conditions, such as the degree of enclosure around the work [Flanagan et al. 2006]. To understand how environmental factors affect exposure levels, the researcher monitored and recorded the test conditions, as described in the following sections.

Water flow: The mass of water flowing into a bucket from the WIN nozzle in one minute was recorded.

Abrasive usage: The company's average sand usage per square foot (ft^2) was used to estimate the amount of sand used per minute. (It was impractical to measure the time between pot fillings as an estimate of sand usage rate, because the workers did not precisely control the amount of abrasive added at each filling.) The company reported sand use of 9.9 pounds/ft^2. In addition, nominal abrasive consumption rates were obtained from Boride Products, manufacturer of the WIN.

Productivity: The amount of surface area treated per day was recorded. A tape measure was used to measure the dimensions of the surface area treated.

Depth of material removed: A caliper was used to estimate the depth of material removed. Where there were indentations in the precast surface formed by the mold, the change in the depth of this indentation was used to estimate the amount of surface removed. The mold controls the consistency of this difference. These indentations were not present on the wall panels at the Crane Way station.

Weather conditions: Weather data were obtained from the Renton Airport, 15 miles southwest of the site. In addition, wind speed was monitored with a portable weather station (Skyview Systems, Chilton Industrial Estate, Sudbury, Suffolk, United Kingdom).

Degree of enclosure: At the large and small blasting stations, the parts were laid on supports about one foot above the ground. Blasting was performed outdoors in unenclosed areas. At the Crane Way station, blasting was performed on a vertically positioned concrete wall panel, creating a one-sided partial enclosure of the blasting process.

Air Monitoring Procedures

Inhalable dust and respirable dust samples were collected during 10 sampling sessions over five days in September 2006. Respirable crystalline silica concentrations were obtained from the respirable dust samples, using x-ray diffraction as described in NIOSH method 7500 [NIOSH 1994b]. The sampling times for individual samples are presented in Appendix I. At the small station and the Crane Way station, some samples were collected over two days to ensure that measurable quantities of crystalline silica would be collected on the filters.

Pre-weighed filters were mounted on a respirable dust cyclone and in an inhalable dust sampler; both samplers were attached at the worker's breathing zone. Tubing was connected from the outlet of each sampler to the inlet of a separate battery-operated pump, through which a known volume of air was drawn. The sampling was task-based, in that sampling was carried out only when abrasive blasting and associated activities were performed. The sampled activities included wet abrasive blasting, periodic cleaning of the surface to review progress in obtaining the desired appearance, and recharging the abrasive blasting pot. The sampling pumps were paused during breaks and between abrasive blasting sessions.

The sampling pumps selected for this study (SKC Universal 224-PCXR4, Eighty-Four, PA) display the total sampling time. These pumps are designed to compensate for pressure losses caused by excessive dust build-up on sample filters; the pump can accommodate pressure losses as large as 5 kilo-pascals (20 inches of water). If the pump can no longer maintain the desired flow rate, it shuts down and the total sampling time is displayed on the pump's LED readout.

Respirable dust concentrations were measured in the breathing zone with personal sampler pumps drawing 4.2 liters per minute (lpm) of air through a cyclone (BGI GK2.69). Respirable dust was collected on an opened-faced 37 mm filter cassette containing a pre-weighed PVC filter mounted on the outlet of the cyclone. This cyclone is used by the United Kingdom's Health and Safety Executive (HSE) to measure respirable dust exposure [Health and Safety Executive 1997]. The minimum sample duration was 200 minutes.

The inhalable dust samples were collected with the Button sampler (P/N 225-360, SKC Inc., Eighty-Four, PA). This sampler draws 4.0 lpm of air through an optional protective cover, a curved wind screen, and a pre-weighed 25 mm filter [Aizenberg et al. 2000]. The wind screen restricts large pieces of debris from reaching and puncturing the pre-weighed filter [Kalatoor et al. 1995].

The mass of material collected on the filters was determined as described by NIOSH method 600 [NIOSH 1994a]. The pre-weighed filters from the respirable dust sampling were analyzed for crystalline silica by x-ray diffraction using NIOSH method 7500 [NIOSH 1994b]. The reported limits of quantitation are 0.01 milligram for gravimetric analysis and for the mass of quartz and cristobalite on filters.

Measurements of background dust were taken to determine the possible contribution of ambient sources to the dust exposures of workers. Possible ambient sources include wind-blown dust and dust disturbed from trucks driving over the sand-covered ground at the site. Dust samples were collected at the western property line and on the west wall of the shed that workers use for breaks.

Data Analysis

The sample results were assumed to be log-normally distributed [Mulhausen and Damiano 1998]. The logarithms of the data were taken, the average and standard deviation were computed, and the inverse logarithms were computed to obtain the geometric mean (GM) and geometric standard deviation (GSD). The GM and GSD of the respirable dust and the respirable crystalline silica concentrations were compared with the silica exposure data compiled by Rappaport et al. [2003] and Flanagan et al. [2006]. A pooled t-test for heterogeneous variances was used to evaluate whether the respirable dust and respirable crystalline silica exposures measured during this study were less than the values reported in these two data compilation studies [Dougherty 1990].

Average exposure levels and confidence limits on the averages were computed for the respirable dust and respirable crystalline silica readings, using methods described elsewhere [Dougherty 1990]. The confidence limits were computed using Lands exact confidence limits.

Video Exposure Monitoring

Video exposure monitoring was performed to evaluate the relationship between dust exposure and the individual worker's tasks and work practices [NIOSH 1992b]. A video camera filmed the abrasive blasting worker's activities while an aerosol photometer (Microdust Pro, Cassella CEL, Bedford, United Kingdom) with a built-in data logger measured dust levels near the worker. This real-time monitoring provided a visual depiction of dust levels generated during various blasting activities. The aerosol photometer was used with an external pump so that the instrumental response to changing concentrations was consistent. The pump had a sampling rate of 4.2 lpm. The video exposure monitoring was conducted for a period of 34 minutes. The output of the aerosol photometer was plotted as a function of time. This plot was annotated to note the activities that occurred when dust levels appeared to be noticeably elevated.

Aerosol photometer measurements also were collected in the dust plumes generated when workers filled the abrasive blasting pot for the small station. The aerosol photometer was mounted on the supports for the bin and was positioned so that it appeared to be in the dust plume (Figure 10). A sampling pump was used to draw 4.2 lpm through the aerosol photometer. This sampling was done for a 3-hour period.

Findings

Sample Results

The results of the air monitoring are summarized in Table 3 and presented in detail in Appendix I. In the personal sample results, the geometric mean respirable dust and respirable crystalline silica exposure levels were, respectively, 0.53 and 0.062 mg/m^3. These levels are lower by a factor of 7 (for respirable dust) and 4 (for respirable crystalline silica) than comparable exposure data compiled by Flanagan et al. [2006] for abrasive blasting. Flanagan et al. [2006] reported a geometric mean of 3.7 mg/m^3 for respirable dust (65 readings) and 0.24 mg/m^3 for respirable crystalline silica (64 readings).

Table 3. Respirable dust, respirable crystalline silica, and inhalable dust sample results: Abrasive blasting with WIN nozzle, Olympian Precast, Redmond, Washington, September 2006

Substance	Number of samples	Geometric mean (mg/m^3)	Geometric std dev	Range (mg/m^3)
personal respirable dust	10	0.53	1.73	0.2 - 1.0
personal respirable crystalline silica	10	0.062	2.01	0.02 - 0.13
area respirable dust	10	0.037	1.32	0.025 - 0.064
area respirable crystalline silica	10	Less than 0.007 - 0.011 mg/m^3		
personal inhalable dust	8	2.40	1.70	1.00 - 4.70
area inhalable dust	8	0.17	1.35	0.098 - 0.24

The Smith-Sauterthwaite t-test for unequal variances was used to evaluate whether the field study respirable crystalline silica and respirable dust concentrations differed significantly from the comparable abrasive blasting exposure data compiled in two recent reports (see Table 1). Table 4 presents the probability that chance caused the observed differences between the field study results and the compiled data in the two cited studies. Clearly, the differences are significant from both a practical and statistical perspective.

Table 4. Probability of chance causing the observed differences between the field study results and the published results in Table 1

Published study	Respirable dust concentrations	Respirable crystalline silica concentrations
Flanagan et al. [2006]	$p < 0.0001$	$p < 0.0001$
Rappaport et al. [2003]	$p < 0.0001$	$p < 0.02$

The average personal TWA result obtained during the field study data and confidence intervals are shown in Table 5.

Table 5. Field study personal respirable crystalline silica results: Average and associated confidence limits

Average	0.077 mg/m^3
Lower 95% confidence limit on average	0.054 mg/m^3
Upper 95% confidence limit on average	0.141 mg/m^3

The levels shown in Table 5 exceed both the NIOSH REL of 0.05 mg/m^3 and the ACGIH TLV (0.065 mg/m^3). However, the NIOSH and ACGIH exposure criteria are based on a full-shift, 8-hour exposure period. In the field study, sampling periods were shorter, ranging from 206 minutes to nearly 8 hours, with an average sample duration of about 5 hours. Ideally, the upper confidence limit on the average exposure should be less than a long-term exposure limit. (The documentation for the current ACGIH TLV for crystalline silica, 0.025 mg/m^3, appears to indicate that the TLV is a long-term exposure limit [ACGIH 2006b].) This exposure level could be achieved by restricting the amount of time that a worker performs wet abrasive blasting. If this administrative control approach is not practical or acceptable, the use of respirators with an assigned protection factor of 10 would appear to provide adequate exposure reduction at the respirable crystalline silica levels found in this study. However, OSHA requires that respirators must be used only as part of a comprehensive respiratory protection program, as set forth in 29 CFR 1910.134, Respiratory protection (directly referenced in the OSHA construction regulation, 29 CFR 1926.103).

The area respirable and inhalable dust concentrations were much lower than the personal exposure results, as shown in Table 3. Based on a Smith-Sauterthwaite t-test for unequal variances, these differences were statistically significant ($p < 0.0001$) [Dougherty 1990]. This finding suggests that extraneous dust from truck traffic did not contribute significantly to the personal exposure levels and that the workers' dust exposures were associated mainly with the abrasive blasting operations.

Aerosol Photometer Measurements

As shown in Figure 11, the normal operation of the abrasive blasting pot creates an obvious source of dust emission. The major spikes in the dust levels seemed to occur every time the pot was filled from the overhanging bin. The workers generally were able to position themselves away from the dust plume. For a 34-minute period, the author taped a worker performing routine wet abrasive blasting and concurrently monitored the dust levels with the aerosol photometer. These results are presented in Figure 12. This figure contains annotations that describe worker activities during the wet abrasive blasting at the large work station. In Figure 12, filling the abrasive blasting pot with sand did not noticeably increase the dust levels recorded by the aerosol photometer. During bin filling, the average aerosol concentration, recorded by the aerosol photometer, was 0.3 mg/m^3, as compared to 1.1 mg/m^3 during the wet abrasive blasting. These results suggest that the bin filling did not contribute significantly to the worker's exposure.

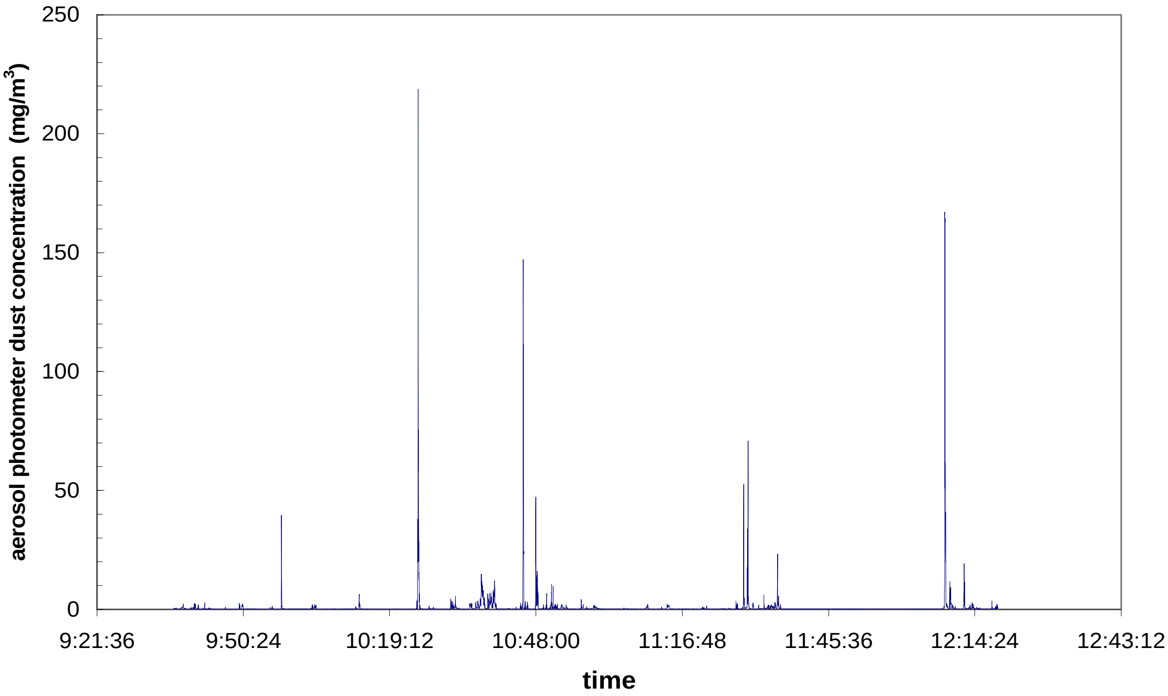

Figure 11. Aerosol photometer measurements collected at stand for charging abrasive blasting pot. Apparently, filling the abrasive blasting pot causes periodic dust emissions.

The dust levels measured by the aerosol photometer during wet abrasive blasting can be affected by water mist. The average dust concentration recorded by the aerosol photometer was 0.9 mg/m^3. This reading is consistent with the inhalable dust levels summarized in Appendix I. Much of the water coating the droplets evaporated, given the dry, warm conditions (air temperature was 75^{o}F and relative humidity was 25%). The estimated droplet evaporation time for 10-50 μm droplets is 0.09 to 2.2 seconds at these conditions [Hinds 2001]. The droplet size is determined by the maximum stable droplet size in the abrasive blasting nozzle. In the nozzle, the air velocities are at least 350 m/sec as the air flow is thought to be supersonic [Settles and Garg 1995]. The maximum stable droplet size is known to be a function of the carrier gas (air) velocity. At an air velocity of 350 m/sec, the maximum stable droplet diameter was estimated to be 5 μm [Lefevre 1989]. This suggests that the water droplets will have a life of less than 0.1 seconds when the relative humidity is less than 50% [Hinds 2001]. This suggests that the aerosol photometer reliably senses abrasive blasting dust. However, it is not possible to be completely certain that the aerosol photometer is sensing only dry particulate debris from abrasive blasting, or a combination of dry particles and residual water droplets.

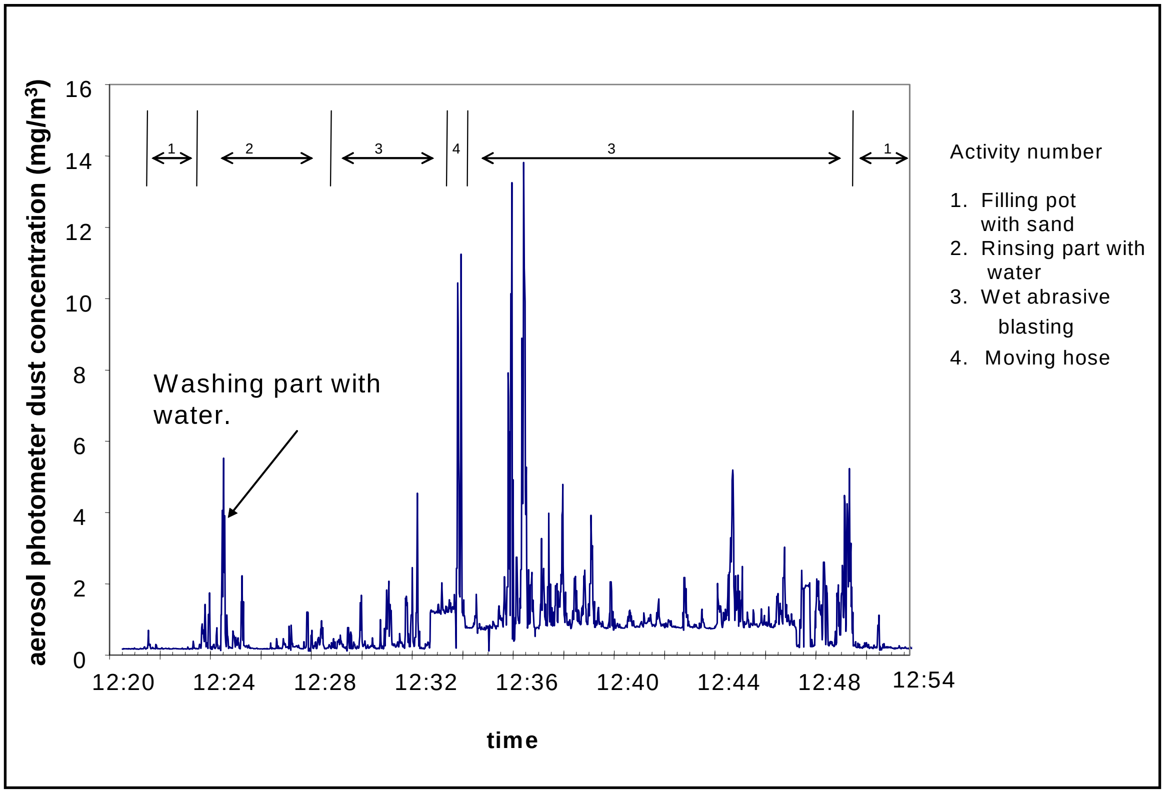

Figure 12. Relative dust concentration measured with an aerosol photometer during wet abrasive blasting. The activity codes are:

1. Filling the abrasive blasting pot with dry sand. This causes a noticeable dust cloud.
2. Using a water hose to rinse debris from pre-cast concrete prior to wet abrasive blasting.
3. Wet abrasive blasting.
4. A brief break in wet abrasive blasting to move the hose.

Test Conditions

Weather conditions during the five days of sampling are summarized in Table 6. The data were obtained from the Renton Airport, about 15 miles southwest of the site. A portable weather station was set up near the small blasting station. The vane anemometer was mostly motionless, indicating that the maximum wind speed was less than 1 to 2 miles per hour. After noon, the wind was generally calm with gusts up to 10 miles per hour.

The abrasive blasting conditions are summarized in Table 7. This information was obtained by interviewing the superintendent and the manager at Olympian Precast. The abrasive blasting pressure is a nominal 80 pounds per square inch of surface area treated. Pressure gauges are not installed at each blasting station.

The water flow is limited by a valve. The water application rates should not be affected by venturi effects caused by a negative static pressure in the throat of the water induction nozzle. The observed water application rate varied from 7 to 19 pounds per minute (water weighs 62.4

pounds per cubic foot or 8.3 pounds per gallon). The areas around the abrasive blasting stations were generally wet the entire day, and water drained from the parts being treated.

The product thickness reduction was measured at the small and large blasting stations. The average thickness and standard deviations are reported in Table 7. The raw data are tabulated in Appendix II. The wet abrasive blasting was done to obtain a certain appearance and the amount of material removed is not controlled. At the Crane Way station, measuring product thickness reduction was impractical, as these products did not have indentations that were controlled by the molds. The product thickness appeared to vary by 0.1-0.2 inch and the product thickness was 4.9 inches. At this location, the wet abrasive blasting was done to obtain a more uniform color and only a minimal amount of material was removed.

The company does not track the mass of abrasive used at each station, but tracks how much abrasive is used per year as well as the square feet of surface area treated. The facility estimated that 9.8 pounds of sand are used per square foot of treated area. This sand application rate was based on calculations of the surface area treated, the sampling time for the task-based air samples, and the factor supplied by the company. In addition, nominal abrasive consumption rates provided by Boride Products, the manufacturer of the nozzle, are listed [Abrasive Blast Nozzle Catalog 2006]. Appendix III indicates that the two abrasive consumption rates at the large and small stations differ considerably. As shown in Figure 12, the workers do not continuously perform wet abrasive blasting. They spend some time adjusting the equipment and cleaning debris from surfaces. Surfaces need to be cleaned to obtain a consistent finish. Furthermore, at regular intervals the workers check their progress toward obtaining the desired finish. In addition, the pressure at each station is not known and may fluctuate with the number of abrasive blasting operations being conducted. Abrasive consumption varies with the blasting pressure.

Table 6. Ambient conditions at Renton Airport, 15 miles from field site in Redmond, Washington

	Max	Min	Average	Standard deviation	Comment
Wind speed (miles per hour)	10.4	0	5.1	2.8	The study site appeared to be very calm until noon each day. The meter indicated a maximum wind speed of zero before noon, and after noon the maximum wind speed was 10 miles per hour. Mostly, the cupped anemometer was motionless.
Temperature (°F)	81	50	64.9	8.6	The temperature was typically 50°F at 7 a.m. and rose to 75-80°F by the end of sampling period.
Relative humidity (%)	89	33	61.6	16.4	Relative humidity was typically 80-89% at 7 a.m. and decreased as temperatures rose during the day.
Dew point (°F)	54	46	50.5	1.8	This is a measure of absolute humidity.

Table 7. Summary of abrasive blasting field site conditions								
Station	**Blasting equipment**	**Description of abrasive blasting process**	**Square feet treated**	**Water application rate, lb/min**	**Average thickness reduction, inches [standard deviation]**	**Nominal nozzle size**	**Estimated sand usage (from company data), lb/min**	**Abrasive consumption rate at 80 psi from Boride Products, lb/min**
Crane Way station	Kelco Model 125	two walls, 345 by 80 inches, light blasting to even color, aggregate not exposed.	383	7.5	Appeared to be under 0.02 inches	8	31	30
Small station	Kelco Model 116	two stair units, aggregate is barely exposed.	123	19	0.03 [0.02]	6	8	16
Large station	Schmidt Mfg. Model 6.5	various smaller wall components, blasted to expose aggregate.	523-286 per day	13	0.04 [0.02]	8	12	30
Nominal blasting pressure is 80 psi. There are no gauges to monitor actual pressure.								

Discussion

The geometric mean respirable dust and respirable crystalline silica exposures found during this study are significantly less than comparable readings reported by Flanagan et al. [2006] and Rappaport et al. [2003]. The maximum respirable crystalline silica reading obtained during this study was 0.13 mg/m^3, the average concentration was 0.077 mg/m^3, and the 95% upper confidence limit on this average exposure was 0.14 mg/m^3. A respirator with an assigned protection factor of 10 would provide appropriate exposure reduction for a worker exposed at this level (0.14 mg/m^3) for a full 8-hour shift. This level of respiratory protection is well below the level typically required to protect workers during abrasive blasting work.

The effectiveness of dust suppression from water application is confounded by the dust control suppression potentially associated with the use of abrasive sand with the fines removed. The abrasive sand used in this study contained 59% crystalline silica, and the crystalline silica measured in the respirable dust samples was less than 20%. Determining the degree to which each factor—water and sand with fines removed—contributed separately to lower dust levels was beyond the scope of the current project. The author recommends controlled laboratory experiments testing the following research hypothesis: *When the fines content of the abrasive is nil, the surface being treated is the source of the respirable crystalline silica exposures*.

The highest respirable dust concentrations were measured at the stations with the lowest water application rate. (The water application rates during wet abrasive blasting appeared to vary from 7 to 19 pounds per minute among the three blasting stations.) In addition to variations in water application rates, variations in dust exposures among these three stations could also be attributed to the different products being treated, as well as differences in the blasting methods. Perhaps controlled testing should be done to develop recommended water application rates.

The wet blasting method used in this study resulted in lower respirable crystalline silica exposures than comparable data reported in the literature. The study suggests that a respirator with a protection factor of 10 could be used for blasting with the WIN, a significant benefit for workers. However, the method also has some drawbacks. Wet abrasive blasting is a messy process. Standing water may be objectionable in some applications and presents obvious safety hazards, for instance during freezing conditions. Furthermore, this process may not be applicable during cold weather because of the potential for ice and snow generation.

Conclusions

At this site, wet abrasive blasting and restricting the fines content of the sand appeared to significantly reduce worker exposure to respirable dust and respirable crystalline silica. However, the effects of these two control approaches are confounded at this site. Controlled laboratory testing is needed to determine the relative importance of each control approach. Furthermore, controlled laboratory testing is needed to develop recommended water application rates for wet abrasive blasting. Excessive water application rates may limit the applicability of this control approach at other operations and sites. Creating mud and large water puddles did not appear to present safety or production problems at this site but could be a problem elsewhere.

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Appendix I. Personal and area concentrations of respirable dust, respirable crystalline silica, and inhalable dust
Olympian Precast, Redmond, Washington
September 5-11, 2006

Date (2006)	Sample description	Personal (p) or Area (a) sample	Respirable dust sampling at 4.2 liters per minute					Inhalable dust sampling at 4 liters per minute		
			Start time	Total time (minutes)	Respirable dust (mg/m^3)	Respirable crystalline silica (mg/m^3)	Fraction silica for respirable dust	Start time	Total time (minutes)	Inhalable dust (mg/m^3)
September 5 and 6	worker at small sand blasting station	p	9:27	349	0.55	0.072	0.13	9:27	349	2.90
September 5	near shed	a	7:40	460	0.033	0.006	0.18	7:40	460	0.17
	worker at large sand blaster	p	7:55	409	0.68	0.075	0.11	7:55	409	1.70
	on west wall about 50 feet from operation	a	7:59	438	0.028	nd[A]		7:59	438	0.13
September 6	near shed	a	7:13	428	0.045	nd[A]		7:13	428	0.22
	large sand blaster	p	7:13	366	0.65	0.124	0.19	7:13	366	3.30
	on west wall some 50 feet from operation	p	7:13	428	0.047	nd		7:13	428	0.10

[A] - not detected, mass on filter below limit of detection

Appendix I. Personal and area concentrations of respirable dust, respirable crystalline silica, and inhalable dust
Olympian Precast, Redmond, Washington
September 5-11, 2006

Date (2006)	Sample description	Personal (p) or Area (a) sample	Respirable dust sampling at 4.2 liters per minute					Inhalable dust sampling at 4 liters per minute		
			Start time	**Total time (minutes)**	**Respirable dust (mg/m^3)**	**Respirable crystalline silica (mg/m^3)**	**Fraction silica for respirable dust**	**Start time**	**Total time (minutes)**	**Inhalable dust (mg/m^3)**
September 6 and 7	worker at Crane Way blasting station	P	12:35	275	0.87	0.087	0.1	12:35	275	4.00
September 7 and 8	worker at small sand blasting station	p	7:15 9/7 8:10 9/8	270	0.36	0.030	0.084	7:15 9/7 8:10 9/8	270	2.40
September 7	near shed	a	7:15	393	0.025	nd[A]		7:19	393	0.24
	worker at large sand blaster	p	7:17	304	0.2	0.0162	0.081	7:20	304	1.50
	on west wall about 50 feet from operation	a	7:17	396	0.033	nd[A]		7:20	396	0.16
September 8	worker at large sand blaster	p	7:28	267	0.32	0.038	0.12	7:28	267	1.00
	on west wall about 50 feet from operation	a	7:08	407	0.033	0.006	0.19	7:08	407	0.19

[A] - not detected, mass on filter below limit of detection

Appendix I. Personal and area concentrations of respirable dust, respirable crystalline silica, and inhalable dust
Olympian Precast, Redmond, Washington
September 5-11, 2006

Date (2006)	Sample description	Personal (p) or Area (a) sample	Respirable dust sampling at 4.2 liters per minute					Inhalable dust sampling at 4 liters per minute		
			Start time	Total time (minutes)	Respirable dust (mg/m^3)	Respirable crystalline silica (mg/m^3)	Fraction silica for respirable dust	Start time	Total time (minutes)	Inhalable dust (mg/m^3)
September 8	break shed	a	7:12	403	0.042	nd[A]		7:12	403	0.21
	worker at Crane Way blasting station	p	10:30	206	1	0.13	0.13	10:35	201	4.70
September 11	worker at large sand blasting station	p	7:20	343	1	0.13	0.13	Inhalable dust samples were not collected on September 11th as there were not enough button samplers.		
	near shed	a	7:00	430	0.033	nd[A]				
	on west wall some 50 feet from operation	a	7:00	427	0.064	0.011	0.17			
	worker performing blasting at small sand blaster and on Crane Way	p	7:45	290	0.34	0.044	0.13			

nd - mass of crystalline silica on filter under 0.01 milligrams.

[A] - not detected, mass on filter below limit of detection

Appendix II. Thickness reduction attributed to abrasive blasting

	Small blasting station	Large blasting station
	0.074	0.039
	0.018	0.009
	0.026	0.067
	0.04	0.038
	0.01	0.056
	0.026	0.05
	0.006	0.011
Average	0.029	0.039
Standard deviation	0.023	0.022
prob> the average thickness reduction differs from zero	0.008	0.002

Appendix III. Surface area treated at large blasting station

date	area (feet^2)
5-Sep	Not recorded
6-Sep	319
7-Sep	353
8-Sep	524
11-Sep	286