In-Depth Survey Report

CONTROL TECHNOLOGY FOR DOWEL DRILLING IN CONCRETE

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EPHB Report No. 347-15a
Springfield-Branson National Airport
Springfield, MO

October, 2011

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Site Surveyed:

Springfield-Branson National Airport
2300 N. Airport Boulevard
Springfield, MO 65802

NAICS Code:

237310 Highway, Street, and Bridge Construction

Survey Dates:

August 1-4, 2011

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Acknowledgements

The authors thank the management of Fred Weber, Inc. and the members of LIUNA Local 663 and IUOE Local 101, whose assistance was essential to the success of this site visit.

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Abstract

Background

Workplace exposure to respirable crystalline silica can cause silicosis, a progressive lung disease marked by scarring and thickening of the lung tissue. Quartz is the most common form of crystalline silica. Crystalline silica is found in several construction materials, such as brick, block, mortar and concrete. Construction tasks that cut, break, grind, abrade, or drill those materials have been associated with overexposure to dust containing respirable crystalline silica. Highway construction tasks that can result in respirable crystalline silica exposures include breaking pavement with jackhammers, concrete sawing, milling pavement, clean-up using compressed air, and dowel drilling. Dowel drilling machines are used to drill horizontal holes in concrete pavement so that dowels can be inserted to transfer loads across pavement joints. NIOSH scientists are conducting a study to assess the effectiveness of dust control systems sold by dowel drill manufactures by measuring exposures to workers operating dowel drills with and without dust controls installed. This site visit was part of that study.

Assessment

NIOSH staff visited the Fred Weber Co. site at the Springfield-Branson National Airport on August 1-4, 2011, and performed industrial hygiene sampling on August 2 and 4, 2011. The sampling measured exposures to respirable dust among two workers that operated five-gang dowel drills to drill holes in a new concrete runway. One worker operated a rented drill, while the other ran a drill owned by the paving contractor. The NIOSH scientists who visited the site also monitored the wind speed and direction, and collected data about the dust controls and the work process in order to understand the conditions that led to the measured exposures.

Results

Air sampling for respirable dust found concentrations that ranged from 1.1 mg/m^3 to 3.3 mg/m^3, 8-hr TWA. For the actual sampling times, TWA respirable dust exposures ranged from 1.7 mg/m^3 to 6.0 mg/m^3. Those actual TWA respirable dust data were assumed to follow a log-normal distribution, with a geometric mean of 3.0 mg/m^3, and a geometric standard deviation of 1.9. Unfortunately, a laboratory error occurred during the analysis of the air samples for respirable crystalline silica. Due to this error, it was not possible to compare the air sampling results to the NIOSH Recommended Exposure Limit for crystalline silica or the OSHA Permissible Exposure Limit for respirable dust that contains greater than 1% quartz (because that limit varies with the quartz content measured in the airborne dust samples). The quartz content in bulk concrete dust samples collected on August 2 and 4, 2011, ranged from 2.2 to 12 percent by weight, with an arithmetic mean quartz content of 6.4 percent. Video exposure monitoring revealed that the practices of reversing air flow through the dust collection system and kneeling near the drills to mark the pavement may have contributed to the measured respirable dust exposures.

The air flows measured at the drills' dust collectors were 1.5 m^3/min (53 cfm) for the rental drill and 1.6 m^3/min (56 cfm) for the company-owned drill. Those flow rates would have resulted in duct velocities of 12 and 13 meters/second (m/sec)(2400 and 2600 feet per minute (fpm)), respectively, excluding the friction losses due to the corrugated duct (the measurements were made with the duct disconnected from the dust collector).

Conclusions and Recommendations

The ACGIH® industrial ventilation manual recommends a transport velocity of 3500 to 4000 fpm for "average industrial dust" (e.g., granite or limestone dust, brick cuttings, silica flour). The observed slower flow rate in the dust control systems may explain the tendency for dust to settle in the corrugated hose and the need to periodically purge the dust collection system with the reverse-pulse to maintain performance.

The purging process resulted from a pulse of reverse high-pressure air flow that blasted clogged concrete dust back out through the hood inlets as well as through any other gaps in the system. The dust clouds that result from the periodic purging of the system seem to defeat the purpose of an industrial ventilation system – to reduce exposures by capturing the contaminant. In other words, it does little good to capture the concrete dust during drilling only to re-aerosolize a portion of it during the purging process. According to the drill manufacturer, the reverse pulse system was not used as intended. The reverse pulse is only designed to remove the dust cake from the filter in the dust collector. Newer models of the same drill are programmed with a 1-second automatic pulse for this purpose.

Options that may help to improve the performance of the dust collection system include increasing the air flow through the system to achieve the recommended transport velocity, using smooth-bore flexible duct, minimizing the use of flexible duct to the extent possible (using rigid duct for long horizontal runs, for example), and emptying the dust collection receptacles more frequently. The length of duct and number of elbows, bends, and sags should be kept to a minimum. In addition, the drill operator should be trained to mark the pavement when the drills are not running or be provided with a long-handled marking device that eliminates the need to bend or kneel to mark the pavement.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Crystalline silica refers to a group of minerals composed of silicon and oxygen; a crystalline structure is one in which the atoms are arranged in a repeating three-dimensional pattern [Bureau of Mines 1992]. The three major forms of crystalline silica are quartz, cristobalite, and tridymite; quartz is the most common form [Bureau of Mines 1992]. Respirable crystalline silica refers to that portion of airborne crystalline silica dust that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm) [NIOSH 2002]. Silicosis, a fibrotic disease of the lungs, is an occupational respiratory disease caused by the inhalation and deposition of respirable crystalline silica dust [NIOSH 1986]. Silicosis is irreversible, often progressive (even after exposure has ceased), and potentially fatal. Because no effective treatment exists for silicosis, prevention through exposure control is essential.

Crystalline silica is a constituent of several materials commonly used in construction, including brick, block, and concrete. Many construction tasks have been associated with overexposure to dust containing crystalline silica [Chisholm 1999, Flanagan et al. 2003, Rappaport et al. 2003, Woskie et al. 2002]. Among these tasks are tuckpointing, concrete cutting, concrete grinding, abrasive blasting, and road milling [Nash and Williams 2000, Thorpe et al. 1999, Akbar-Kanzadeh and Brillhart 2002, Glindmeyer and Hammad 1988, Linch 2002, Rappaport et al. 2003]. Highway construction tasks that have been associated with silica exposures include jackhammer use, concrete sawing, milling asphalt and concrete pavement, clean-up using compressed air, and dowel drilling [Valiante et al. 2004]. Linch [2002] also identified dowel drills as sources of dust emissions on highway construction sites.

Dowel drilling machines (or dowel drills) are used to drill horizontal holes in concrete pavement. Steel dowels transfer loads between adjacent concrete pavement slabs [Park et al. 2008]. They are typically used in "transverse joints in rigid airport and highway pavement to transfer shear from a heavily loaded slab to an adjacent less heavily loaded slab" [Bush and Mannava 2000]. Typical dowel drilling machines have one or more drills held parallel in a frame that aligns the drills and controls wandering [FHWA 2006]. The dowel drilling machine may be self propelled or boom mounted, and may ride on the slab or on the subbase [FHWA 2006]. After drilling to a typical depth of 23 cm (9 inches (in)) the anchoring material is placed, and the dowel is installed. The diameter of the hole is determined by the dowel diameter and whether cement-based grout or an epoxy compound is used to anchor the dowels [FHWA 2006].

The study by Valiante et al. [2004] reported that dowel drilling respirable crystalline silica exposures ranged from 0.05 milligrams per cubic meter (mg/m^3) to 0.16 mg/m^3, 8-hour (hr) time weighted average (TWA). Linch [2002] also documented silica exposures during dowel drilling. The Linch [2002] study reported 8-hr TWA quartz exposures for an operator and laborer using a boom-mounted dowel drilling machine. The operator's 8-hr TWA exposure ranged from less than the minimally detectable concentration[1] of 0.029 mg/m^3 to 0.11 mg/m^3, with a geometric mean respirable crystalline silica exposure of 0.037 mg/m^3 for 8 samples. The highest result was 2.2 times the NIOSH Recommended Exposure Limit (REL) for crystalline silica of 50 micrograms per cubic meter ($\mu g/m^3$). The laborer's 8-hr TWA respirable crystalline silica exposures ranged from 0.12 -1.3 mg/m^3 (2.4 – 26 times the NIOSH REL), with a geometric mean of 0.24 mg/m^3 (4.8 times the NIOSH REL) for

[1] The minimally detectable concentration is the analytical limit of detection divided by the sample volume [Hewett and Ganser 2007]. Linch [2002] reported an LOD for quartz on filters of 0.01 mg/sample and a sample volume of 350.2 L for an operator's sample.

8 samples. Linch [2002] concluded his study of dowel drilling exposures with this statement:

> Means of controlling the respirable dust generated from concrete drilling during all operations needs to be developed, tested, and employed. Pneumatic drilling is the common method of drilling concrete pavement. Methods of using small amounts of water through the drill stem should be developed for these specific applications. High-velocity dust collection systems that effectively control respirable dust should be tested and made available.

There are only two American manufacturers of dowel drills, E-Z Drill, Inc. and Minnich Manufacturing. Both manufacturers offer optional dust control systems for their machines. The manufacturers both make local exhaust ventilation (LEV) dust control systems to capture the dust generated by the dowel drilling process. In addition, they both sell water kits to suppress the dust that results from drilling holes for dowels. One manufacturer's water kit supplies water through the drill steel, while the other manufacturer's water kit sprays water on the surface to be drilled. NIOSH research aims to evaluate the effectiveness of current dust controls for dowel drilling machines, work with manufacturers to improve dust controls if necessary, and promote the use of tools with dust controls.

Three approaches were planned to evaluate the effectiveness of current dust controls. The first measured respirable dust emissions from dowel drilling machines in a controlled setting, isolated from the effects of wind, weather, and other sources of particulate, assessing the effectiveness of the controls in reducing emissions. Emissions with and without the use of controls were compared. The second approach collected current data on respirable dust and crystalline silica exposures associated with dowel drilling without dust controls because the most recent dowel drilling exposure studies were published more than five years ago [Linch 2002, Valiante et al. 2004]. The third approach, including this survey, will assess personal respirable dust and respirable crystalline silica exposures of workers operating dowel drilling machines with dust controls in place in a real-world setting to determine the ability of the dust controls to limit exposures.

Background for this Survey

In order to assess the effectiveness of the dust controls, it was necessary to evaluate exposures at a site where dust controls were used during dowel drilling. This survey was performed on August 1-4, 2011 at Springfield-Branson National Airport in Springfield, MO. An opening meeting and site walkthrough were performed on August 1, 2011. Sampling was conducted on August 2 and 4, 2011, to assess the extent of respirable dust and crystalline silica exposure while workers used dowel drills equipped with dust controls to drill holes in concrete pavement. The drilling was done as part of the renovation of the airport's runway 14-32 (Figure A1 in the Appendix is an airport diagram). On August 3, no drilling was performed. The NIOSH researchers collected data on the dowel drills' dust collection systems on that day.

The Federal Aviation Administration [FAA 2009] requires dowel drilling during runway construction, either using rotary-type core drills or rotary-type percussion drills. Contractors reportedly do not use core drills for this task because: 1) they leave a core that must be extracted from a blind hole (one that doesn't pass completely through the concrete); 2) the core may break in the hole, requiring the eventual use of a percussion drill to remove it; 3) core drills are slower, and; 4) core drills utilize water as a coolant, which mixes with concrete dust to create a slurry that must be collected, and wets the hole, which interferes with the epoxy used to anchor the dowel rods.

Plant and Process Description

Introduction

Fred Weber, Inc. is a full-service heavy and highway construction firm founded in 1928 by Fred Weber, Sr. Their headquarters is located in Maryland Heights, Missouri. Concrete and asphalt paving projects are a major focus of Fred Weber, Inc.'s work. They employ over 1,400 people in a variety of construction trades.

Process Description

Dowel drilling was performed by two construction workers on August 2 and one construction worker on August 4. Drilling was not conducted on August 3 because the concrete had not cured sufficiently. On August 2, each worker operated an identical 5-gang on-slab dowel drill (model A5SC, Minnich Manufacturing Company, Inc., Mansfield, OH). Worker 1 operated a company-owned drill (s/n 3159-26). Worker 2 operated a rental drill (s/n 1964-21) (Figure 1). On August 4, only one drill was used. Worker 1 ran the company-owned drill on that day (Figure 2). Both drills were equipped with the drill manufacturer's dust collection system.

Figure 1 - Worker Operating the Rental Drill, the Same Make and Model as the Company-Owned Drill

Figure 2 - Worker Operating the Company-Owned Drill

The drills used Whirlibits to drill horizontal holes 38cm (15 in) on center, 28.6 mm (1⅛ in) in diameter and 24 cm (9½ in) deep into the side of the new 38 cm (15 in) concrete runway slab. The work cycle consisted of moving the drill and compressor, drilling the holes, marking the slab for the next set of holes, and moving the drill and compressor into position.

The workers wore hardhats, safety vests, safety glasses, ear plugs, and work boots. They sometimes wore N-95 filtering facepiece respirators. Fred Weber Co. provides the respirators for optional use by the workers as part of their respiratory protection program.

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended Occupational Exposure Limits (OELs) when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a TWA exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have a recommended Short Term Exposure Limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA Permissible Exposure Limits (PELs) [29 CFR[2] 1910.1000 2003a] are occupational exposure limits that are legally enforceable in covered workplaces under the Occupational Safety and Health Act. NIOSH recommendations are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the Threshold Limit Values (TLVs®) recommended by American Conference of Governmental Industrial Hygienists (ACGIH®), a professional organization [ACGIH® 2010a]. ACGIH® TLVs® are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” Workplace Environmental Exposure Levels™ (WEELs) are recommended OELs developed by the American Industrial Hygiene Association® (AIHA®), another

[2] *Code of Federal Regulations. See CFR in references.

professional organization. WEELs have been established for some chemicals “when no other legal or authoritative limits exist” [AIHA® 2007].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Crystalline Silica Exposure Limits

When dust controls are not used or maintained or proper practices are not followed, respirable crystalline silica exposures can exceed the NIOSH REL, the OSHA PEL, or the ACGIH® TLV®. NIOSH recommends an exposure limit for respirable crystalline silica of 0.05 mg/m^3 as a TWA determined during a full-shift sample for up to a 10-hr workday during a 40-hr workweek to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2002]. When source controls cannot keep exposures below the NIOSH REL, NIOSH also recommends minimizing the risk of illness that remains for workers exposed at the REL by substituting less hazardous materials for crystalline silica when feasible, by using appropriate respiratory protection, and by making medical examinations available to exposed workers [NIOSH 2002]. In cases of simultaneous exposure to more than one form of crystalline silica, the concentration of free silica in air can be expressed as micrograms of free silica per cubic meter of air sampled ($\mu g/m^3$) [NIOSH 1975].

$$\mu g\, SiO_2/m^3 = \frac{\mu g\, Q + \mu g\, C + \mu g\, T + \mu g\, P}{V} \qquad (1)$$

Where Q is quartz, C is cristobalite, and T is tridymite, and P is “other polymorphs.”

The current OSHA PEL for respirable dust containing crystalline silica for the construction industry is measured by impinger sampling. In the construction industry, the PELs for cristobalite and quartz are the same. The PELs are expressed in millions of particles per cubic foot (mppcf) and calculated using the following formula [29 CFR 1926.55 2003b]:

$$\text{Respirable PEL} = \frac{250\ \text{mppcf}}{\%\ \text{Silica} + 5} \qquad (2)$$

Since the PELs were adopted, the impinger sampling method has been rendered obsolete by gravimetric sampling [OSHA 1996]. OSHA currently instructs its compliance officers to apply a conversion factor of 0.1 mg/m^3 per mppcf when converting between gravimetric sampling and the particle count standard when characterizing construction operation exposures [OSHA 2008].

The ACGIH® TLV® for α-quartz and cristobalite (respirable fraction) is 0.025 mg/m^3 [ACGIH® 2010a].

Methodology

Sampling Strategy

This evaluation focused on task-based sampling, in order to quantify the exposure associated with the dowel drilling task. The total sampling times reflect the period sampled while the workers were dowel drilling and may not reflect the length of the workers' daily shift. For example, on August 2, when the workers completed the drilling assigned for the day, one worker said that he would help place the fabric underlayment for the next concrete pour. On August 4, the worker completed drilling his assigned holes on the sides of the runway during the sampling period, but drilled additional holes in the end of the runway after sampling ended. Partial-period consecutive samples were collected to avoid the potential for sample loss due to overloading or equipment failure associated with the use of full-period single samples [NIOSH 1977].

Sampling Procedures

Air Sampling

Personal breathing zone air samples for respirable particulate were collected at a flow rate of 2.2 liters/minute (L/min) using battery-operated sampling pumps (Aircheck Sampler model 224, SKC, Inc., Eighty Four, PA) calibrated before and after each day's use. A sampling pump was clipped to each sampled employee's belt worn at their waist. The pump was connected via Tygon® tubing and a tapered Leur-type fitting to a pre-weighed, 37-mm diameter, 5-micron (μm) pore-size polyvinyl chloride filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band (in accordance with NIOSH Methods 0600 and 7500) [NIOSH 1998, NIOSH 2003]. The front portion of the cassette was removed and the cassette was attached to a Higgins-Dewell type respirable dust cyclone (model BGI4L, BGI Inc., Waltham, MA). At a flow rate of 2.2 L/min, the BGI4L cyclone has a 50% cut point of (D_{50}) of 4.37 μm [BGI 2003]. D_{50} is the aerodynamic diameter of the particle at which penetration into the cyclone declines to 50% [Vincent 2007]. The cyclone was clipped to the sampled employee's vest near their head and neck (Figure 3). Bulk samples of dust were also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

Figure 3 - Sampler in Worker's Breathing Zone and Pump at his Waist

The filter samples were analyzed for respirable particulates according to NIOSH Method 0600 [NIOSH 1998]. The limit of detection was 70 µg/sample. The limit of quantitation was 230 µg/sample. The results in this report were corrected for laboratory and field blanks.

Crystalline silica analysis of filter samples was performed using X-ray diffraction according to NIOSH Method 7500 [NIOSH 2003] with modifications. Each filter was removed from its cassette and placed in a ceramic crucible, which was covered with a ceramic lid. The crucibles were loaded into a muffle furnace to ash the filters. The muffle furnace temperature was gradually increased to 800 °C, held at that temperature for 1 hour, and then allowed to cool to room temperature. In NIOSH Method 7500, the crucibles are heated to 600 °C for 2 hours, unless graphite is present.

In the lab, 10 mg of sodium chloride was added to the contents of each crucible and a pestle was used to thoroughly grind the mixture. After grinding, the pestle was rinsed into the crucible with deionized water. Then, 1 mL of a 0.5% solution of Triton X-100 was added to each crucible. In contrast, NIOSH Method 7500 instructs the analyst to add several mL of 2-propanol to the ash, scrape the crucible with a glass rod to loosen all particles and transfer the residue to a 50-mL beaker, wash the crucible several more times and add the wash to the beaker. The analyst is then instructed to add 2-propanol to the beaker to bring the volume to about 15 mL.

The next step in NIOSH Method 7500 is to cover the beaker with a watchglass and agitate in an ultrasonic bath for at least 3 min. The suspension is then observed to make sure that the agglomerated particles are broken up. The underside of the watchglass is washed with 2-propanol, and the washings are collected in the beaker.

In the lab and in NIOSH Method 7500, a silver membrane filter was placed in the vacuum filtration unit. In the lab, 2 mL of deionized water was placed on the filter followed by the sample suspension, three crucible rinsings, and a final rinse with isopropanol. In the NIOSH Method, 2 to 3 mL of 2-propanol is poured onto the silver filter. The sample suspension is then poured from the beaker into the funnel. Then, the beaker is rinsed several times and the rinsings are added to the funnel for a total volume of 20 mL.

Vacuum was applied to deposit the suspension onto the filter. The silver membrane filter was then transferred to an aluminum sample plate and placed in the automated sample changer for analysis by X-ray diffraction. NIOSH Method 7500 instructs the analyst to place 2 drops of 1.5% parlodion solution on a glass slide, remove the silver filter with forceps, and fix the material to the filter by placing the bottom side of the filter in the parlodion solution. The sample is then dried on top of a heated Teflon sheet prior to mounting in the XRD sample holder. The lab reported LODs for quartz, cristobalite and tridymite were 5 µg/sample, 10 µg/sample, and 10 µg/sample, respectively. The LOQs for quartz, cristobalite and tridymite were 17 µg/sample, 33 µg/sample, and 33 µg/sample, respectively. The results in this report were corrected for laboratory and field blanks.

Bulk samples were not analyzed in accordance with NIOSH Method 7500. Preparation and analyses began by weighing approximately 2 mg of each sample into a ceramic crucible. Next, 10 mg of sodium chloride was added to each crucible and the mixture was ground using a pestle. The pestle was rinsed into the crucible with 5 mL of de-ionized water. Potential interferences were removed by adding 2 mL of concentrated nitric acid to the mixture in each crucible and heating the crucibles on a hot plate for 5 minutes at 95 °C. The samples were allowed to cool before 1 mL of a 0.5% solution of Triton X-100 was added to each crucible. The samples were then sonicated for 5 minutes. Two mL of de-ionized water was placed on a 25-mm diameter silver membrane filter in a vacuum filtration unit, after which the sample suspension was deposited on the filter. This was followed by three crucible rinsings and a final isopropanol rinse. Vacuum was applied to deposit the suspension on the filter, which was transferred to an aluminum sample plate for analysis by X-ray diffraction. The LOD for quartz in bulk samples was 0.3%. The LODs for cristobalite and tridymite were 0.5%. The LOQ for quartz in the bulk samples was 0.83%. The LOQs for cristobalite and tridymite were 1.7%.

Video Exposure Monitoring

Respirable dust exposures in real-time were assessed using a Personal Dataram (Model pDR-1000AN, Thermo Electron Corp., Franklin, MA). The pDR is a nephelometer that uses light scattering to produce a measure of dust over a size range of 0.1-10 µm and a concentration range of 0.001 to 400 mg/m^3. These readings are relative to a gravimetric calibration performed by the manufacturer in mg/m^3 using standard SAE fine (ISO fine) test dust. For this survey, the pDR was programmed to record the average dust concentration once every second.

A video camera was paired with the direct reading instrument, and video exposure monitoring techniques were used to characterize exposure [NIOSH 1992]. In the laboratory, the data collected with the pDR were overlaid onto the video recording to observe the effects of factors such as work practices on exposure. Figure 4 shows the worker wearing the pDR on the strap of an empty backpack. A web belt looped around his neck and under one arm was also used to hold the pDR.

Figure 4 - Worker Wearing pDR

Measurement of Dust Control Flow Rate

Exhaust air flow rates were measured using a Sierra Instruments, Inc. (Monterey, CA) model 730-N5-1 fast response in-line mass flow meter (range 0-2.83 m^3/min (0-100 cfm)). A Sierra Instruments, Inc. Model 954 Flo-Box was used to read the signal from the meter. Flow measurements were made at the dust collector at the inlet for the number 1 drill on the rental rig and the number 5 drill on the company-owned rig. This was done for convenience when the drills were parked side-by-side on the slab.

Air flow measurements required an extended straight inlet into the dust collector. A 5 cm (2 in) to 5 cm (2 in) flexible coupling (Model RC 50, American Valve, Greensboro, NC) was used to attach a 30 cm (12 in) long piece of PVC-DWV Schedule 40 pipe to the dust collector inlet. A threaded 5 cm (2 in) to 5 cm (2 in) adapter connected the pipe to the outlet of the mass flow meter. A second threaded 5 cm (2 in) to 5 cm (2 in) adapter was connected to the intlet of the mass flow meter. This adaptor was attached to a 27 cm (10½ in) long piece of PVC-DWV Schedule 40 pipe. The other end of that pipe was open to the atmosphere (Figure 5).

Figure 5 - Air Flow Measurement Device on Company-Owned Drill

Weather Monitoring Methods

The NIOSH researchers used a data-logging weather station (Kestrel 4500, Nielsen-Kellerman, Boothwyn, PA) mounted on top of a tripod to assess weather conditions at the site. The weather meter was approximately 1.5 m (60 in) off the ground; about breathing zone height [NIOSH 2010]. On August 2, the tripod was placed alongside the runway under construction. On August 4, the tripod was positioned on the runway section itself. The weather meter was programmed to record data every 10 minutes. Airport weather observations from the Springfield-Branson National Airport weather station (KSGF) were gathered from the local National Oceanic and Atmospheric Administration (NOAA) office and the Internet as a back-up.

Average wind direction was calculated using the equation [EPA 2000]

$$\bar{\theta}_{RV} = ArcTan\left(V_x/V_y\right) + FLOW \qquad (3)$$

$$FLOW \begin{array}{l} = +180; for\ ArcTan\left(V_x/V_y\right) < 180 \\ = -180; for\ ArcTan\left(V_x/V_y\right) > 180 \end{array} \qquad (4)$$

Where

$$V_x = -\frac{1}{N}\sum \sin\theta_i \qquad (5)$$

And

$$V_y = -\frac{1}{N}\sum \cos\theta_i \qquad (6)$$

$\bar{\theta}_{RV}$ is the resultant mean wind direction

V_x is the magnitude of the east-west component of the unit vector mean wind

V_y is the magnitude of the north-south component of the unit vector mean wind

θ_i is the azimuth angle of the wind vector, measured clockwise from north (i.e., the wind direction)

N is the number of observations

In spreadsheet programs, use of the function ATAN2 avoids the extra checks needed to insure that V_x and V_y are nonzero, and are defined over a full 360 degree range [EPA 2000].

Due to an equipment set-up error, the cover was left on the impeller on the weather station on August 2. Wind speed data for that day were obtained from the local NOAA office. The 10 meter wind speed data from NOAA were corrected for the 1.5 meter height of the NIOSH wind monitor using the equation [EPA 2000]

$$U_z = U_r(Z/Z_r)^p \qquad (7)$$

Where

U_z is the scalar mean wind speed at height z above ground level

U_r is the scalar mean wind speed at some reference height Z_r, typically 10 m

p is the power-law exponent

The site-specific power law exponent was determined using two levels of wind data collected on August 4 (10 m NOAA data and 1.5 m NIOSH data) using the equation [EPA 2000]

$$p = \frac{ln(U) - \ln(U_r)}{ln(Z) - ln(Z_r)} \qquad (8)$$

Measuring Productivity

Productivity was measured by counting the number of holes drilled during each sampling period on each work day.

Control Technology

Each of the bits was surrounded by a close-capture hood at the work surface. Each hood take-off was attached to a length of 5 cm (2 in) diameter corrugated flexible hose (the interior surface is corrugated as well). The other end of the hose was attached to a dust collector at the back of the dowel drill unit. There were five hoods and three dust collectors on the units used at the Springfield-Branson National Airport. Hoods 1 and 2 were attached to the dust collector on the left, hood 3 was connected to the middle dust collector, and hoods 4 and 5 were served by the dust collector on the right. Suction is provided by a pneumatic transfer pump (an eductor). There are two each on the left and right dust collector and one on the center dust collector. A 2 in deep pleated Merv 13 cartridge filter (P/N P148646-016-340, Donaldson Company, Inc., Bloomington, MN) in each dust collector traps the dust captured by the hood and transported to the collector through the hose. The filters were not inspected during this survey. The dust build-up collected on the filter falls into a five gallon plastic bucket attached to the bottom of each dust collector. Periodically, the workers manually reversed the air flow through the dust collection system to purge settled dust from the hoods and hoses and remove the dust cake from the filter. Newer models of the same drill use a timed reverse pulse system to remove the dust build up on the filters. The pulse is 1 second in duration. The workers emptied the five gallon buckets daily.

The extensive use of flexible duct leads to sags in long horizontal runs and where the duct transitions from horizontal to vertical or changes direction (Figures 6, 7, and 8). Dust collects in those sags as drilling takes place. In addition, dust builds on the filter. When the dowel drill operator notices that the dust collection system's performance is falling off, he manually purges the filters and hoses by reversing the air flow through the system. This practice creates large clouds of dust (Figure 9). One operator reported that he was instructed to purge the system after every set of five holes.

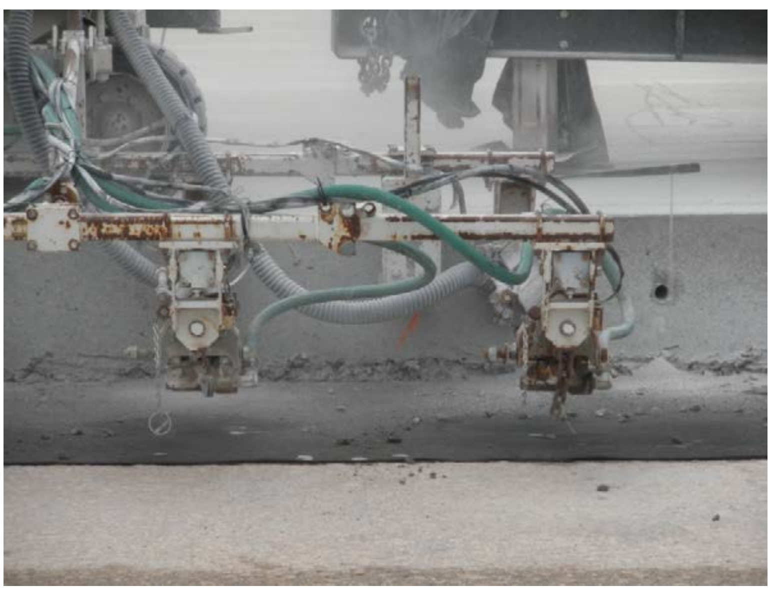

Figure 6 - The Exhaust Hose Sags in Horizontal Runs Near the Hoods

Figure 7 - The Flexible Duct Sags in Long Runs

Figure 8 - The Flexible Duct Forms a Loop When it Changes Direction. Note the Hose Connected to the Left Side of the Dust Collector on the Right.

Figure 9 - Purging Creates Clouds of Dust

Results

Table 1 presents the bulk sampling results. The air sampling results are reported in Tables 2 and 3. This evaluation focused on task-based sampling in order to quantify the respirable dust and silica exposures associated with the dowel drilling task. The total sampling times in Tables 2 and 3 may not reflect the length of the workers' daily shift. For example, on August 2, both workers were assigned to other tasks after they completed their assigned drilling work. The tables in the Appendix provide the sampling data used to calculate the results provided in Tables 2 and 3.

Silica Content in Bulk Samples

One bulk sample was collected for every air sample collected on both workers. The bulk samples were collected from settled dust near the holes drilled by the workers during the corresponding air sampling period. An additional bulk sample was collected from one of the dust collector buckets on the employer-owned drill on August 4, 2011. The quartz content of the bulk samples is reported in Table 1, below. No cristobalite or tridymite were detected in any of the bulk samples. The quartz content in the bulk samples ranged from 2.2 to 12 percent by weight, with an arithmetic mean quartz content of 6.4 percent.

Table 1 – Quartz Content of Bulk Dust Samples

Date	Worker	Sample Period	Quartz %
8/2/2011	1	1	7.7
8/2/2011	1	2	2.2
8/2/2011	2	1	3.1
8/4/2011	1	1	8.7
8/4/2011	1	2	12
8/4/2011	1	bucket	4.4

Respirable Dust Results

Table 2 reports the respirable dust results for all of the air samples. Table 3 presents the TWA respirable dust results. Eight-hour TWAs were calculated assuming that no further exposure occurred during the unsampled portion of the workday [OSHA 2008]. This was the case for both workers on August 2. Worker 1 drilled a small number of additional holes after the sampling period ended on August 4.

Respirable dust exposures ranged from to 1.1 mg/m^3 to 3.3 mg/m^3, 8-hr TWA. For the actual sampling times, TWA respirable dust exposures ranged from 1.7 mg/m^3 to 6.0 mg/m^3. Those actual TWA respirable dust data were assumed to follow a log-normal distribution, with a geometric mean of 3.0 mg/m^3, and a geometric standard deviation of 1.9.

Table 2 – Respirable Dust Sampling Results

Date	Worker	Sample Period	Sampling Time (minutes)	Respirable Dust Concentration (mg/m^3)
8/2/2011	1	1	248	0.31
8/2/2011	1	2	72	6.3
8/2/2011	2	1	264	6.0
8/4/2011	1	1	238	0.094
8/4/2011	1	2	235	5.2

Notes: mg/m^3 means milligrams per cubic meter.

Table 3 – Respirable Dust TWA Results

Date	Worker	Sampling Time (minutes)	Respirable Dust TWA Concentration (mg/m^3)	Respirable Dust 8-Hour TWA Concentration (mg/m^3)
8/2/2011	1	320	1.7	1.1
8/2/2011	2	264	6.0	3.3
8/4/2011	1	473	2.6	2.6

Notes: mg/m^3 means milligrams per cubic meter.

Respirable Crystalline Silica Results

The first step in the analysis of silica dust on filter samples is to digest the PVC filters used to collect the samples. There are several ways to digest the filters, including ashing the samples in a muffle furnace or dissolving the filters in tetrahydrofuran. Using the muffle furnace in the presence of calcite (limestone) in a silica sample creates a negative interference by forming calcium silicate. This means that the X-ray diffractometer doesn’t detect the crystalline silica in the samples. There is a step in the analytical method to deal with the presence of limestone if a muffle furnace is used, but that relies on the lab using the bulk samples to identify interferences. That didn’t happen here.

The bulk samples and air samples were analyzed differently. The bulk concrete dust was digested with nitric acid, which would dissolve any limestone, despite instructions to analyze the bulks first to identify interferences. The interference check, as written in NIOSH Method 7500, instructs the lab to analyze the bulk sample directly by X-ray diffraction, without any preparation. This step would probably have identified the presence of limestone in the dust, allowing suitable analyses of the air samples. Because this step was not accomplished, the interference was not identified, the analysis of the air samples was not modified to deal with the interference, and the crystalline silica content in the air samples could not be quantified.

Video Exposure Monitoring Results

Two brief sequences of video exposure monitoring were performed while worker 1 operated the company-owned dowel drill on August 4, 2011. The first set of data was collected from 8:51 a.m. to 9:16 a.m. (morning). The second set of data was collected from 2:30 to 2:56 p.m. (afternoon). Review of the video recording with the data overlay indicated that one of the spikes in respirable dust exposure was associated with worker 1 marking the pavement during drilling. The pavement is marked to position the drill. This spike probably occurred because he knelt down close to the drills while they were running to make the mark (Figure 10). Another task that resulted in a spike in exposure was purging the dust collection system, which involved manual operation of the reverse-pulse system to purge dust from the filters, ducts, and hoods (Figure 11). The tasks of moving the drill and drilling did not produce the spikes seen with marking and purging (Figures 12 and13). Note also the different scales used on the right side of the figures between the afternoon (Figures 10, 11, and 13) where a 0-200 mg/m^3 scale was used , and morning tasks (Figure 12) where a 0-10 mg/m^3 scale was used, reflecting an order of magnitude difference in the intensity of the exposures. The dust concentration recorded by the pDR can also be seen in the blue numerals in the box at the top of the figure (e.g., 51.6 mg/m^3 in Figure 10). The green numbers are minutes and seconds that correspond to the time displayed in the lower left of the figure.

Figure 10 - Marking the Concrete During Drilling Produced a Spike in Respirable Dust Exposure

Figure 11 - Purging the Dust Collection System Produced a Spike in Respirable Dust Exposure

Figure 12 - Moving the Drill Did Not Result in a Spike in Respirable Dust Exposure

Figure 13 - The Drilling Task Did Not Result in a Spike in Respirable Dust Exposure

Dust Control Flow Rate Results

Ten air flow readings were obtained from the inlet of the dust collector for the number 1 drill on the rental drill and number 5 drill on the company-owned drill. The average air flow rate for the rental drill operated by worker 2 was 1.5 m^3/min (53 cfm). The average air flow rate for the company-owned drill operated by worker 1 was 1.6 m^3/min (56 cfm).

Weather Monitoring Results

Matching the wind speed and direction to the workers' sampling periods resulted in the data shown in Table 4. Table 5 presents the wind speed and direction for both workers' drilling days (i.e., averaged over their total sampling periods). Figures 14 and 18 are airport diagrams that show the direction of travel and approximate location of the drills on August 2 and August 4, 2011. Figures 15-17, 19 and 20 are plots of wind direction for each sampling period on both days. The shaded areas in the wind direction plots indicate the direction the wind arrives at the runway.

The plots of wind direction for August 2 (Figures 15 and 16) show that for worker 1, the wind was blowing toward the front of the dowel drill and the worker during the first sampling period. While the second sample was collected, the wind blew from the back of the dowel drill toward the worker. For worker 2, Figure 17 shows that the wind also blew from the back of the dowel drill toward the worker while his sample was collected. The results in Table 2 indicate that wind blowing from the back of the dowel drill produced similar respirable exposures for both workers.

Figure 19 shows that the wind was blowing toward the front of the drilling machine during the first sampling period on August 4. During the second sampling period, Figure 20 illustrates that the wind was blowing at the side of the machine, almost parallel to the runway. Based on the position of the worker and the direction of travel, the worker would have been standing downwind of the drilling machine during that time. Unfortunately, there were not enough samples collected to determine whether the wind speed and direction had a statistically significant effect on the measured dust exposures.

Table 4 – Wind Speed and Direction by Worker and Sample Period

Date	Worker	Sample Period	Average Wind Speed (kph)	Average Wind Speed (mph)	Average Wind Direction (degrees)
8/2/2011	1	1	13	8	200
8/2/2011	1	2	10	6	247
8/2/2011	2	1	13	8	217
8/4/2011	1	1	13	8	71
8/4/2011	1	2	14	9	158

Notes: kph is kilometers/hour, mph is miles/hour

Table 5 – Wind Speed and Direction by Worker and Drilling Day

Date	Worker	Average Wind Speed (kph)	Average Wind Speed (mph)	Average Wind Direction (degrees)
8/2/2011	1	13	8	211
8/2/2011	2	13	8	217
8/4/2011	1	14	9	121

Notes: kph is kilometers/hour, mph is miles/hour

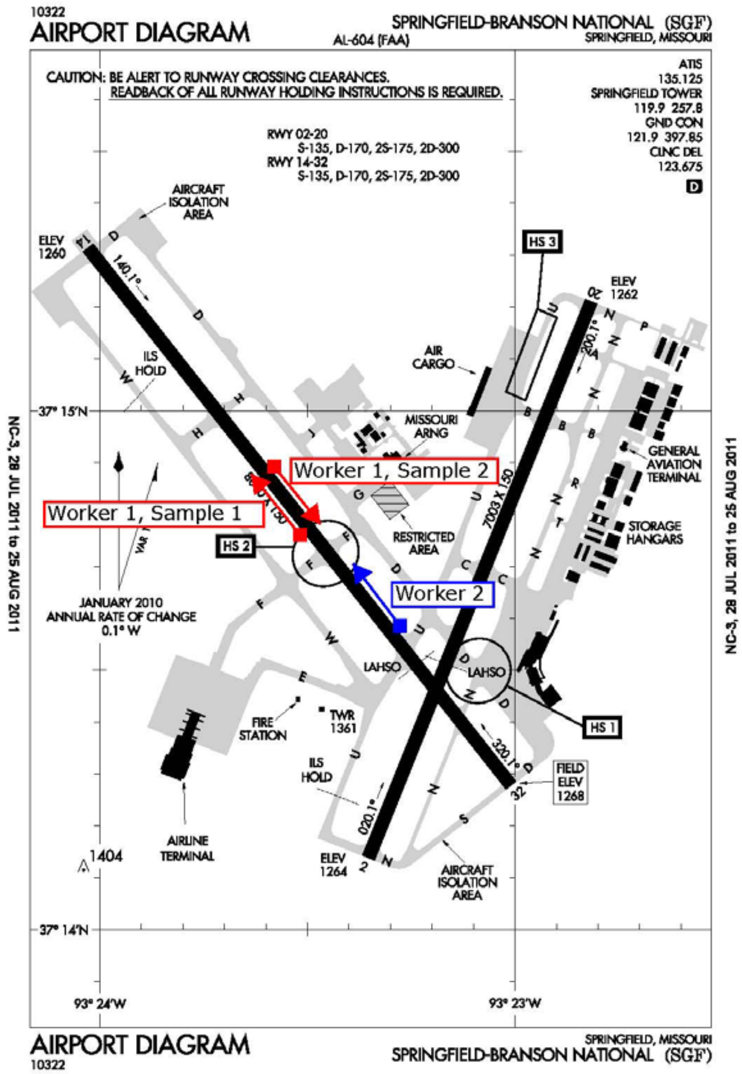

Figure 14 - Airport Diagram Showing Approximate Location and Direction of Travel for Drills on August 2, 2011

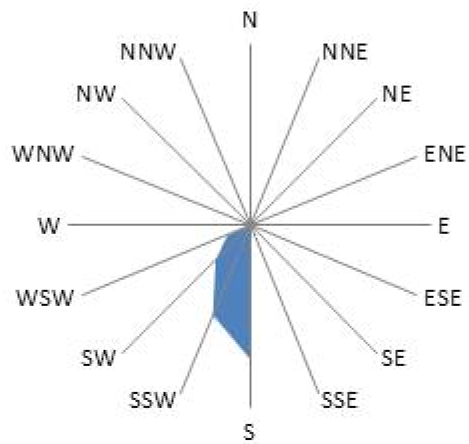

Figure 15 - Wind Direction on August 2, 2011, Worker 1, Sample 1

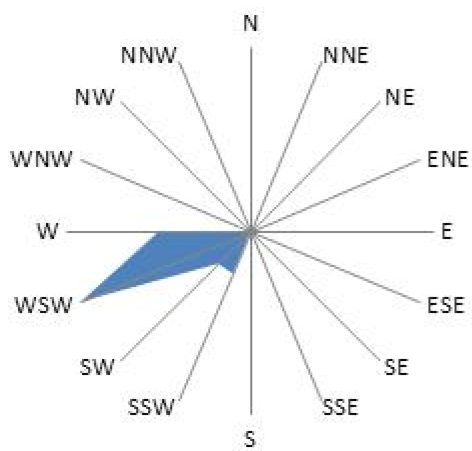

Figure 16 - Wind Direction on August 2, 2011, Worker 1, Sample 2

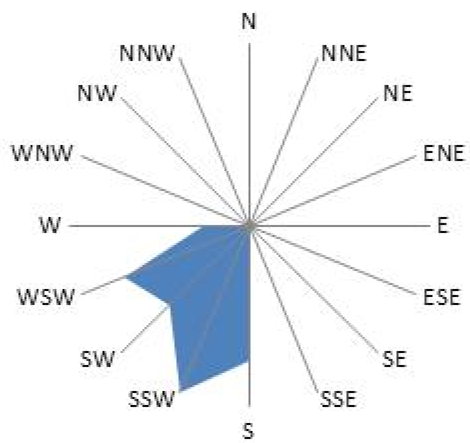

Figure 17 - Wind Direction on August 2, 2011, Worker 2, Sample 1

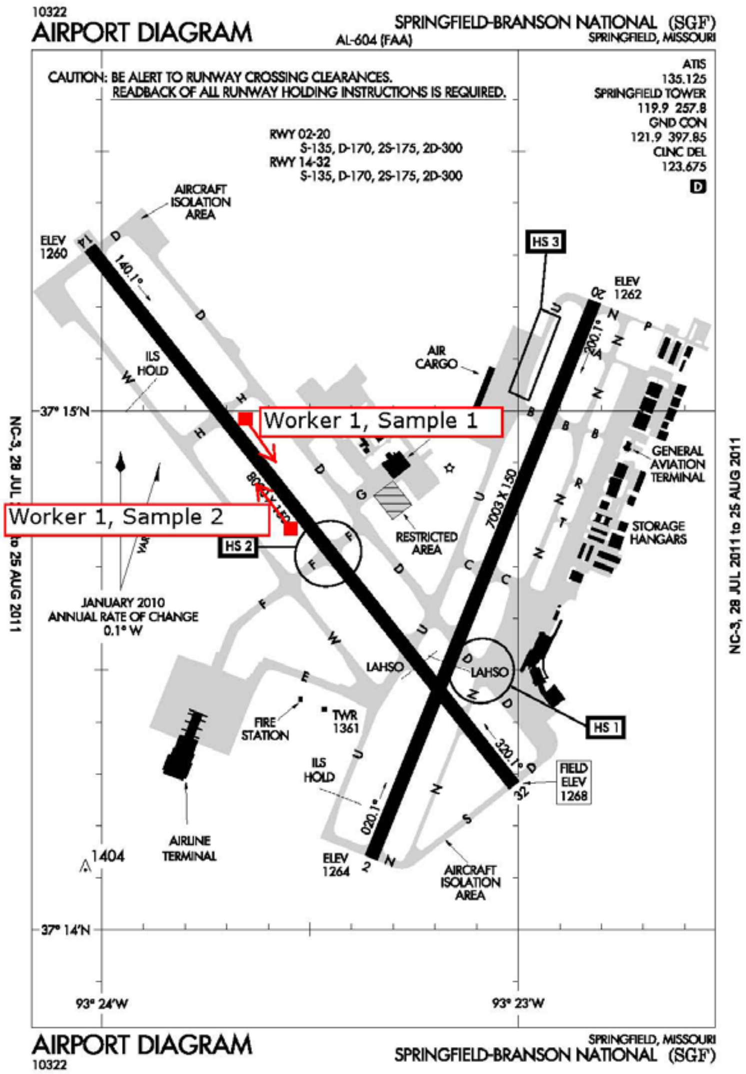

Figure 18 - Airport Diagram Showing Approximate Location and Direction of Travel for Drill on August 4, 2011

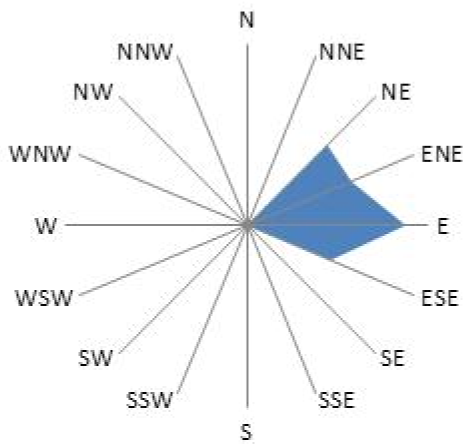

Figure 19 - Wind Direction on August 4, 2011, Worker 1, Sample 1

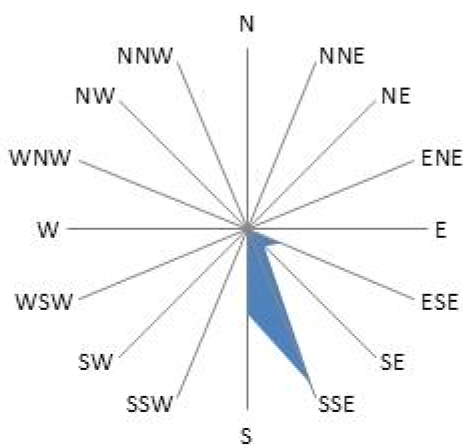

Figure 20 - Wind Direction on August 4, 2011, Worker 1, Sample 2

Productivity Results

Worker 1 drilled 681 holes August 2 and 1070 holes on August 4. On August 2, Worker 2 drilled 781 holes. Worker 1 was slowed by a number of broken bits on August 2. Table 6 provides the number of holes drilled for each sampling period on August 2 and 4, when those data were recorded. There was also downtime associated with maintenance, fueling the compressor, and turning the drills around (e.g., to cross the runway).

Table 6 – Number of Holes Drilled by Date, Worker, and Sample Period

Date	Worker	Sample Period	Holes Drilled
8/2/2011	1	1	555
8/2/2011	1	2	126
8/2/2011	2	1	781
8/4/2011	1	1	475
8/4/2011	2	2	595

Conclusions and Recommendations

Unfortunately, the laboratory error that occurred when the silica samples were analyzed means that the dust sampling results cannot be compared to any OELs. The OSHA PEL for respirable dust that contains silica varies depending upon the silica content in the dust samples, which was not determined due to the error. The results reported here can't be compared to the NIOSH REL for crystalline silica because the silica content in the dust collected on the filter samples was not determined. The ACGIH® TLVs® for particles not otherwise specified and Portland cement do not apply to these samples because they almost certainly contained crystalline silica, even if the amount was not determined.

The geometric mean respirable dust exposures for the dowel drill operators reported here (3.0 mg/m^3) were similar to the geometric mean respirable dust exposures measured at an airport runway dowel drilling site where no dust controls were in use (3.25 mg/m^3) [Echt et al. 2011a]. However, the range of TWA exposures was narrower on this site (1.7 mg/m^3 to 6.0 mg/m^3) than on the site where no dust controls were in use (0.445 mg/m^3 to 21.2 mg/m^3). Two 4-gang dowel drills from two different manufacturers were in use at that site. The difference in ranges may indicate that the dust control technology is capable of preventing extremely high exposures. Unfortunately, because of the laboratory error in the silica sample analysis, it is not possible to determine if the dust control technology was able to achieve compliance with applicable exposure limits.

In 2010, NIOSH investigators measured emissions with a Minnich 5-gang drill enclosed in a tent to evaluate the effectiveness of the dust control without the effects of the wind and isolated from diesel exhaust emissions from the compressor

[Echt et al. 2011 b]. Under those circumstances, the geometric mean of the "control on" respirable dust samples ranged from 4.7 mg/m^3 at the center to 6.6 mg/m^3 in front of the drill array. The "control off" geometric mean respirable dust concentrations were 59 mg/m^3 at the front and center sampling locations and 53 mg/m^3 at the rear of the machine. Those results indicated that the dust control was able to reduce geometric mean respirable dust emissions by 89% to 92%, effectively blunting high emissions, but producing respirable dust results not very different from those seen in this field survey (the difference may be due to the use of the tent in the previous study).

The dust control systems on the dowel drills used on this site, like all local exhaust ventilation systems, consist of hoods, ducts, air cleaners, and air movers [ACGIH® 2010b]. The hoods surround the steel and bit at the work surface. They collect the concrete dust, which is produced in an air stream directed toward the hood. Flexible ducts convey the dust and air to the air cleaner. The air cleaner contains a cartridge filter to remove the contaminant from the airstream. The air mover must produce the desired air flow to carry the dust despite losses due to friction, fittings, bends, and hood entry [ACGIH® 2010]. Minnich uses pneumatically induced eductors to move the air in their system. The air flows measured at the drills' dust collectors, 1.5 m^3/min (53 cfm) for the rental drill and 1.6 m^3/min (56 cfm) for the company-owned drill, would have resulted in duct velocities of 12 and 13 meters/second (m/sec)(2400 and 2600 feet per minute (fpm)), respectively, excluding the friction losses due to the corrugated duct (the measurements were made with the duct disconnected from the dust collector). The ACGIH® industrial ventilation manual recommends a transport velocity of 3500 to 4000 fpm for "average industrial dust" (e.g., granite or limestone dust, brick cuttings, silica flour) [ACGIH® 2010]. The observed slower flow rate in the Minnich system may explain the tendency for dust to settle in the corrugated hose and the need to periodically purge the dust collection system with the reverse-pulse to maintain performance.

The purging process resulted from a pulse of reverse high-pressure air flow that blasted clogged concrete dust back out through the hood inlets as well as through any other gaps in the system (e.g., where the buckets meet the dust collectors). The dust clouds that result from the periodic purging of the system seem to defeat the purpose of an industrial ventilation system – to reduce exposures by capturing the contaminant. In other words, it does little good to capture the concrete dust during drilling only to re-aerosolize a portion of it during the purging process.

According to the drill manufacturer, the reverse pulse system was not used as intended. The reverse pulse is only designed to remove the dust cake from the filter in the dust collector. Newer models of the same drill are programmed with a 1-second automatic pulse for this purpose. The manually-operated reverse pulse system should be operated for the same duration.

For trouble-shooting purposes, the drill manufacturer noted that dust coming out of the rain caps on top of the dust collectors indicates that the filter is not seated properly. Dust emissions around the bucket indicate that the bucket is full. Dust escaping around the close capture hoods indicates a loss of suction somewhere in the system. Dust that collects in the exhaust hoses should be removed manually, for example, by raising and lowering the drill array.

Options that may help to improve the performance of the dust collection system include increasing the air flow through the system to achieve the recommended transport velocity, using smooth-bore flexible duct, and minimizing the use of flexible duct to the extent possible (using rigid duct for long horizontal runs, for example). The length of duct and number of elbows, bends, and sags should be kept to a minimum.

The five gallon buckets used to collect the dust are handy, durable, and easy to obtain. However, because they are white and the dust is light gray, it is difficult to determine when the buckets are full. This is important because the dust collected on the filter needs to go somewhere to keep the system operating as intended. The use of translucent five gallon plastic buckets, if they are commercially available, might make it easier for the operator to determine how frequently to empty the buckets to maintain the ventilation system's performance. A clear plastic collar could also be installed between the bottom of the dust collector and the top of the bucket. If translucent buckets are not available or a clear plastic collar is not feasible, it would be worthwhile to check the buckets periodically to determine how often they need to be emptied in order to establish a schedule.

An alternative approach is to use the volume of the concrete removed from the holes and the production rate to determine how quickly the buckets fill. A hole 28.6 mm (1⅛ in) in diameter and 24 cm (9½ in) deep contains about 151 cubic centimeters (9.2 cubic inches) of concrete. Previous NIOSH research [Echt et al. 2011 b] showed that the Minnich 5-gang drill captured at least 89% of the dust, or 8.2 cubic inches (134 cubic centimeters) per hole. Based on the number of holes drilled in Table 6, and the sampling times in Table 2, it takes approximately 2.2 minutes to drill a hole (the sampling times included moving, set-up, and delays included in drilling during these shifts). That means that the two dust collectors that serve two drills each collect 7.4 cubic inches of concrete/minute, a rate that would fill a 5-gallon bucket in about 156 minutes. That means that the buckets must be emptied about every 2.5 hours to maintain the dust collection system's performance. However, the pulverizing action of the percussion drills will cause the dust to occupy a greater volume than the solid concrete that filled the hole. The 2.5 hour figure probably represents a maximum time to fill the buckets. Experience may show that they need to be emptied more often.

Installing a static pressure gauge across the filter would give the drill operator information on when the filter needed to be replaced. A static pressure gauge installed near each hood would indicate when the system was clogged with dust. NIOSH would be willing to work with the paving contractor and the drill manufacturer to help implement any of these recommendations.

N-95 filtering facepiece respirators were available if the workers wanted to wear them. If N-95 filtering facepiece respirators are worn properly and used in accordance with good practices, they may be used to reduce respirable crystalline silica exposures to acceptable levels when exposures do not exceed 10 times the occupational exposure limit [NIOSH 2008]. NIOSH recommends (and it is mandated by OSHA where the use of respirators is required) that respirators in the workplace be used as part of a comprehensive respiratory protection program. The program should include written standard operating procedures; workplace monitoring; hazard-based selection; fit-testing and training of the user; procedures for cleaning, disinfection, maintenance, and storage of reusable respirators; respirator inspection and program evaluation; medical qualification of the user; and the use of NIOSH-certified respirators [NIOSH 1987]. In addition, no facial hair is allowed that interferes with the face-to-facepiece seal [NIOSH 1987, 29 CFR 1910.134 2003c].

These provisions may be difficult to comply with in the construction industry. This suggests that engineering control technology would be the preferred method to reduce exposures associated with dowel drilling. Air sampling should be conducted with the engineering controls in use to determine if respiratory protection is still needed to reduce exposures to acceptable concentrations.

Finally, video exposure monitoring showed that the practice of bending or kneeling to mark the pavement while the drills are running adds to the operator's exposure. The operator should be trained to mark the pavement when the drills are not running or be provided with a long-handled marking device that eliminates the need to bend or kneel to mark the pavement.

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Appendix

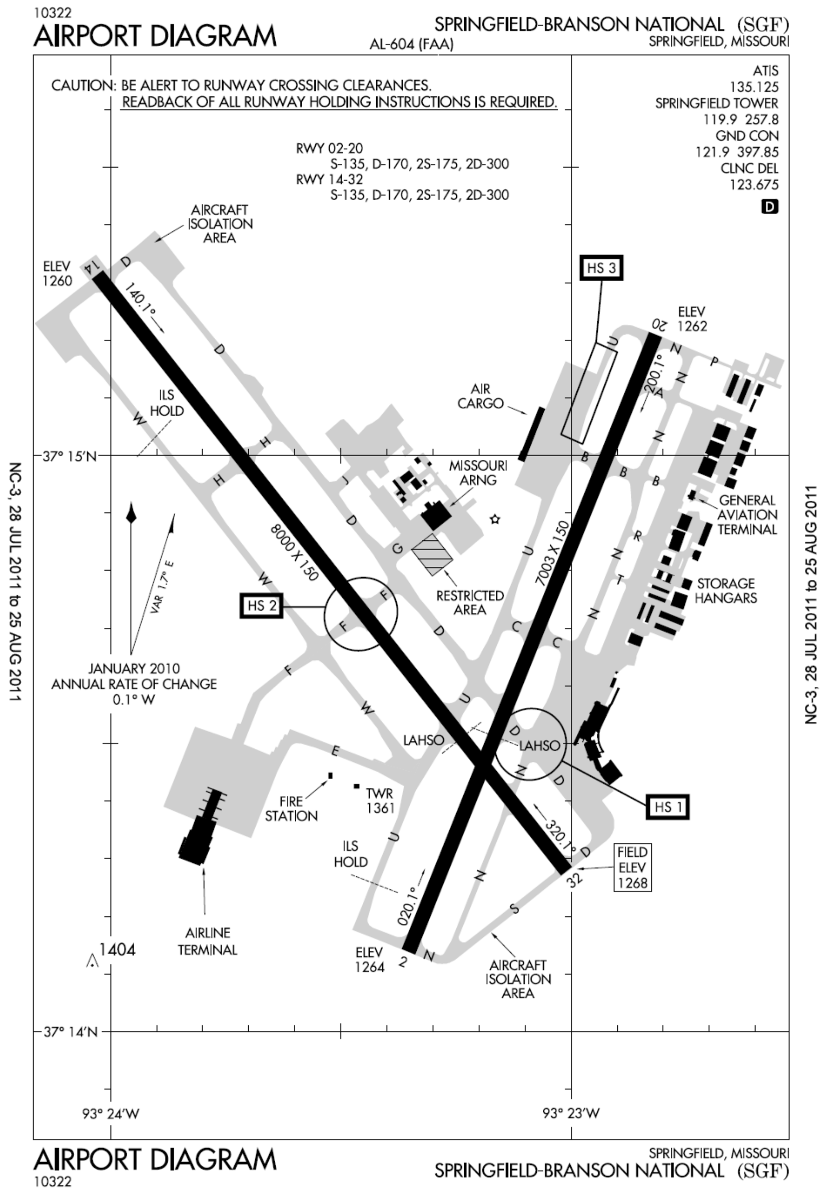

Figure A1 - Airport Diagram. Drilling on August 2 and 4, 2011 Took Place on Runway 14-32 [FAA 2010].

Table A1 - Respirable Dust Sampling Results

Date	Worker	Sampling Period	Duration (minutes)	Volume (Liters)	Respirable Particulate (µg/sample)	Respirable Concentration (mg/m^3)
8/2	1	1	248	542	(170)	0.314
8/2	1	2	72	157	990	6.31
8/2	2	1	264	603	3600	5.97
8/4	1	1	238	524	ND	<0.0945
8/4	1	2	235	518	2700	5.21

Notes: µg means micrograms, and mg/m^3 means milligrams/cubic meter. Numbers in parentheses were between the limit of detection and the limit of quantitation. These are trace values with limited confidence in their accuracy. ND indicates a result less than the limit of detection (LOD). A value of LOD/√2 was used to calculate the concentration [Hornung and Reed 1990], which is noted with a < sign.

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