In-Depth Survey Report

CONTROL TECHNOLOGY FOR DOWEL DRILLING IN CONCRETE

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
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Site Surveyed:

Columbus Municipal Airport
4770 Ray Boll Blvd
Columbus, IN 47203

NAICS Code:

237310 Highway, Street, and Bridge Construction

Survey Dates:

August 17, 24, and 25, 2010

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Table of Contents

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 E&B Paving site at the Columbus, Indiana municipal airport on August 17, 24, and 25, 2010 and performed industrial hygiene sampling which measured exposures to respirable dust and respirable crystalline silica among two workers that operated dowel drills to drill holes in a new concrete runway. The NIOSH scientists also monitored the wind speed and direction at the site, and collected data about the work process in order to understand the conditions that led to the measured exposures.

Results

Air sampling for respirable dust and crystalline silica showed that on two of the three days, both workers were exposed to respirable quartz at concentrations that exceeded the NIOSH Recommended Exposure Limit of 0.05 mg/m^3. The air sampling also showed that on one day, both workers were exposed to respirable dust in excess of the OSHA Permissible Exposure Limit for respirable dust that contains greater than 1% quartz, and that one worker's exposure exceeded that limit on a second day (the OSHA Permissible Exposure Limit varies depending upon the percent quartz measured in the dust).

Conclusions and Recommendations

The concentrations of respirable dust and respirable crystalline silica measured during dowel drilling indicated that the potential for overexposure exists when no dust controls are used. The measured exposures indicate that dust controls should be installed on the dowel-drilling machines. In the absence of dust controls, respirators should be used to reduce exposures.

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.

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-pin drilling machines (or dowel drilling machines) 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-pin drilling machines have one or more drills held parallel in a frame that aligns the drills and controls wandering [FHWA 2006]. The dowel-pin 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 diameter of the hole is determined by the dowel diameter and the use of cement-based grout or epoxy anchoring formulations), the anchoring material is placed, and the dowel is installed [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-pin 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-pin drilling machines, work with manufacturers to improve dust controls if necessary, and promote the use of tools with dust controls.

Three approaches are planned to evaluate the effectiveness of current dust controls. The first will measure 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 will be compared. The second approach 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. The third approach, including this survey, will collect 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].

Background for this Survey

In order to assess the effectiveness of the dust controls, it was necessary to gather baseline data by evaluating exposures at a site where no dust controls were used during dowel drilling (as is typically the case). This survey was performed on August 17, 24, and 25, 2010 at Columbus Municipal Airport in Columbus, Indiana. Sampling was conducted to assess the extent of respirable dust and crystalline silica exposure from drilling holes for dowel rods in concrete with no dust controls during renovation of the airport's runway 5-23 (Figure A1 in the Appendix is an airport diagram). 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, creating a slurry that must be collected, and wetting the hole, which interferes with the epoxy used to anchor the dowel rods.

Plant and Process Description

Introduction

E&B Paving, a subsidiary of Irving Materials, Inc., is headquartered in Anderson, Indiana. The paving company performs a range of services, including asphalt and concrete paving, asphalt milling, and excavation. E&B Paving was incorporated in 1967 by Jack Euratte and Richard Bedwell with a plant located in Muncie, Indiana. The paving company employs more than 1,000 full-time and seasonal employees.

Process Description

Dowel drilling was performed by three construction laborers on all three days of sampling. One laborer operated a Minnich 4-drill, on-slab dowel-pin drill (model A-4SC, Minnich Manufacturing, Inc., Mansfield, OH). Two other laborers, working together, operated an E-Z Drill 4-drill, on-slab dowel-pin drill (model 210-3 SRA, E-Z Drill, Inc., Stillwater, OK). One laborer stood on the slab, operating the controls of the E-Z Drill rig. The other laborer stood on the grade, guiding the positioning of the drill and checking the depth of the holes drilled.

Figure 1 - Laborer Operating a Minnich Dowel Drill

Figure 2 - Laborer Operating an E-Z Drill Dowel Drill

Both drills used Whirlibits (model x31628, Brunner & Lay, Inc., Springdale, AR) to drill horizontal holes 28.6 mm (1⅛ inches) in diameter and 24 cm (9.5 inches) deep into the side of the new concrete runway slab. Eleven holes were drilled in every 7.62 m (25 feet) of the slab. The work cycle consisted of positioning the machine, drilling the holes, advancing the machine, and positioning for the next set. Workers wore workboots, reflective shirts, and ear muffs. N-95 filtering facepiece respirators were available, but were not always used (one worker used his with only one of the two straps). One of the machine operators had a beard. E & B Paving, Inc. requires fit testing for other operations and exposures as part of a comprehensive respiratory protection program, but it did not require it for this operation at the time of the study (i.e., it does now).

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 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,

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

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 (μg/m^3) [NIOSH 1975].

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

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].

For the purposes of this survey, when the workday exceeded eight hours, the model developed by Brief and Scala [1975] was used to adjust the PEL and TLV®. The conservative Brief and Scala model results in the calculation of a reduction factor, expressed as:

$$\mathrm{RF} = \frac{8}{\mathrm{h}} \times \frac{24 - \mathrm{h}}{16} \qquad (3)$$

Where RF is the reduction factor and h is the actual work shift time in hours. The occupational exposure limit (e.g., the PEL or TLV®; the numbers 10 and 14 are substituted for 8 and 16, respectively, for the REL when the work shift exceeds 10 hours) is multiplied by the reduction factor to arrive at an adjusted occupational exposure limit.

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. The results may not reflect the entirety of their silica exposures during the work day, either. For example, if they performed another potentially dusty task during the unsampled period, that exposure was not evaluated and is not included in the TWA calculation. 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 top near their head and neck. Bulk samples of dust were also collected in accordance with NIOSH Method 7500 [NIOSH 2003].

The filter samples were analyzed for respirable particulates according to NIOSH Method 0600 [NIOSH 1998]. The filters were allowed to equilibrate for a minimum of two hours before weighing. A static neutralizer was placed in front of the balance (model AT201, Mettler-Toledo, Columbus, OH) and each filter was passed over the neutralizer before weighing. The limit of detection was 40 µg/sample. The limit of quantitation was 120 µg/sample. The results in this report were corrected for laboratory and field blanks.

Crystalline silica analysis of filter and bulk samples was performed using X-ray diffraction according to NIOSH Method 7500 [NIOSH 2003]. Each filter was removed from the sampling cassette and transferred to a 15 milliliter (mL) vial. Then, 10 mL of tetrahydrofuran (THF) was added to each vial. The samples were allowed to stand for five minutes then vortexed for two minutes. After vortexing, the samples were placed in an ultrasonic bath and sonicated for ten minutes. Next, a silver membrane filter was placed in the vacuum filtration unit. Then, 2 mL of THF was placed on the filter followed by the sample suspension, three vial rinsings, and a final vial cap rinse. Finally, 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. The LODs for quartz, cristobalite and tridymite were 5 µg/sample, 5 µg/sample, and 10 µg/sample, respectively. The LOQs for quartz, cristobalite and tridymite were 17 µg/sample, 17 µg/sample, and 33 µg/sample, respectively. The results in this report were corrected for laboratory and field blanks.

Weather Monitoring Methods

On August 17, the NIOSH researchers used a weather meter that belonged to the employer (Kestrel 4500, Nielsen-Kellerman, Boothwyn, PA). The weather meter was mounted on top of a tripod, which was placed next to the runway under construction. The weather meter was programmed to record data every 10 minutes. On August 23 and 24, the NIOSH researchers used a HOBO Weather Station Data Logger (model H21-001, Onset Computer Corporation, Pocasset, MA), which was placed atop a tripod at the end of the runway under construction. The weather meter was programmed to record data every 15 minutes. Airport weather observations from the Columbus Airport weather station (Columbus/Bakalar, IN [KBAK]) were gathered from the Internet as a back-up.

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

$$\bar{\theta}_{RV} = ArcTan\,(V_x \;\; V_y) + FLOW \qquad (4)$$

$$FLOW \begin{array}{l} = +180; for\ ArcTan\,(V_x/V_y)<180 \\ = -180; for\ ArcTan\,(V_x/V_y)>180 \end{array} \qquad (5)$$

Where

$$V_x = -\frac{1}{N}\sum \sin\theta_i \qquad (6)$$

And

$$V_y = -\frac{1}{N}\sum \cos\theta_i \qquad (7)$$

$\bar{\theta}_{RV}$ 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)

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].

Measuring Productivity

Productivity was measured by counting the number of holes drilled during each sampling period and during all three work days.

Control Technology

No engineering control technology to control dust from dowel drilling was used during this site visit. Walk-behind (pedestrian-guided) concrete saws equipped with water sprays were used to make partial cuts through the new concrete portions of the runway to control cracking. A water truck was used occasionally to suppress dust generation due to vehicle traffic on roadways adjacent to the newly-poured runway segments.

Results

This evaluation focused on task-based sampling, in order to quantify the respirable dust and silica exposures associated with the dowel drilling task. The data in Table 1 were used to calculate percent quartz in the samples to compute the respirable dust PELs, which were then adjusted (based on equation 3, above) when the total sampling time exceeded eight hours. The total sampling times in Tables 2 and 3 may not reflect the length of the workers' daily shift and the results may not report the entirety of their respirable dust or crystalline silica exposures during the work day. For example, Laborer 1 spent the first part of the third sampling day (August 25, 2010) using a hand-held pneumatic rock drill to re-drill defective holes from the previous day. While some respirable dust and silica exposure may have resulted from that task, his use of the hand-held drill was not sampled or included in the total sampling time or TWA calculation. The tables in the Appendix provide the sampling data used to calculate the results provided in Tables 1–3.

Silica Content in Air and Bulk Samples

Table 1 presents the respirable crystalline silica and respirable dust masses reported for every air sample collected during this survey. For Laborer 1 and Laborer 2, the sum of the respirable crystalline silica masses for each sample included in each day's TWA is divided by the sum of the respirable dust masses for those samples and multiplied by 100 to calculate the percent silica over the workday. That value is used to calculate the OSHA PEL [OSHA 2008].

$$\% \text{ Silica} = \frac{\text{Sample}_1 \text{ Silica Mass } (\mu g) + \cdots + \text{Sample}_n \text{ Silica Mass } (\mu g)}{\text{Sample}_1 \text{Dust Mass } (\mu g) + \cdots + \text{Sample}_n \text{ Dust Mass } (\mu g)} \text{ x } 100 \qquad (8)$$

Table 1 – Respirable Dust Masses, Respirable Silica Masses and Percent Silica

Date	Laborer	Sample Period	Respirable Quartz (µg/sample)	Respirable Dust (µg/sample)	Quartz %
8/17/2010	1	1	140	4100	3.4
8/17/2010	1	2	230	9000	2.6
8/17/2010	1	3	160	4100	3.9
8/17/2010	2	1	150	4800	3.1
8/17/2010	2	2	100	3000	3.3
8/17/2010	2	3	48	1400	3.4
8/17/2010	2	4	54	1500	3.6
8/17/2010	2	5	32	920	3.5
8/17/2010	2	6	(14)	210	6.7
8/24/2010	1	1	120	3000	4.0
8/24/2010	1	2	61	1700	3.6
8/24/2010	1	3	(16)	440	3.6
8/24/2010	1	4	36	920	3.9
8/24/2010	2	1	57	1700	3.4
8/24/2010	2	2	18	420	4.3
8/24/2010	2	3	ND	(67)	---
8/24/2010	2	4	ND	(77)	---
8/25/2010	1	1	27	750	3.6
8/25/2010	1	2	(6.8)	130	5.2
8/25/2010	1	3	(8.9)	270	3.3
8/25/2010	2	1	ND	ND	---
8/25/2010	2	2	ND	ND	---
8/25/2010	2	3	(5.6)	150	3.7
8/25/2010	2	4	(12)	290	4.1

Notes: µg means microgram. Numbers in parentheses indicate values between the limit of detection and the limit of quantitation, which should be considered trace values with limited confidence in their accuracy. ND means the result was less than the limit of detection.

Based on the data presented in Table 1 and using equation 8, on August 17, Laborer 1's air samples contained 3.1% quartz and Laborer 2's air samples contained 3.4% quartz. On August 24, Laborer 1's air samples contained 3.8% quartz, while Laborer 2's air samples contained 3.7% quartz. Laborer 1's air samples contained 3.7% quartz on August 25. The air samples collected on Laborer 2 on August 25 contained 4.0% quartz.

Overall, the air samples contained from 2.6 to 6.7% quartz, with a mean of 3.3% quartz. Bulk samples of concrete dust were collected each day. One bulk sample was collected near each worker each day. Two bulk samples collected on August 17 contained 7.7 and 13% quartz. Two bulk samples collected on August 24 contained 7.1 and 10% quartz. Two bulk samples collected on August 25 contained 6.9 and 9.9% quartz. No cristobalite or tridymite were detected in any of the bulk samples.

The laboratory reported cristobalite between the limit of detection and the limit of quantitation in four air samples (two for Laborer 1 and one for Laborer 2 on August 17, and one for Laborer 1 on August 24). However, cristobalite has a significant interference from aluminum phosphate ($AlPO_4$) which could be present in concrete. Since the secondary line used to identify cristobalite also has a significant interference from aluminum phosphate, there is no way to analytically identify cristobalite separately from $AlPO_4$ using X-ray diffraction. No cristobalite in the bulk samples would also indicate that no cristobalite would be present in the air. The positive results for cristobalite in the air samples were most likely the result of analytical interference from $AlPO_4$.

Respirable Dust Results

As noted above, the quartz content in the laborers' respirable dust samples ranged from 3.1% to 4.0%, resulting in unadjusted PELs from 3.1 mg/m^3 to 2.8 mg/m^3. Table 2 reports the TWA respirable dust results, eight hour TWA respirable dust results, PELs and adjusted PELs where the laborers' sampling times exceeded eight hours. 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 Laborer 2 on all three days and for Laborer 1 on the first and last day.

Respirable dust exposures ranged from less than the PEL for both workers on August 25 and less than the PEL for Laborer 2 on August 24 to 5 times the PEL for an 8-hr TWA exposure for Laborer 1 on August 17. It should be noted that Laborer 1 wore a fourth sample on August 17, but the sampling line was disconnected for an undetermined time so the total sample volume could not be reliably determined. The fourth sample was not included in any of the TWA calculations or subsequent analyses. Based upon the available data, the high respirable dust exposure measured for Laborer 1 on August 17 could not be fully explained due to the wind or a specific operating condition.

Overall, TWA respirable dust exposures ranged from 0.445 mg/m^3 to 21.2 mg/m^3. The TWA respirable dust data followed a log-normal distribution, with a geometric mean of 3.25 mg/m^3, a geometric median of 3.43 mg/m^3, and a geometric standard deviation of 3.98 mg/m^3.

Table 2 – Respirable Dust Results

Date	Laborer	Sampling Time (minutes)	Respirable Dust TWA Concentration (mg/m^3)	Respirable Dust 8-Hour TWA Concentration (mg/m^3)	OSHA PEL (mg/m^3)	Adjusted PEL
8/17/2010	1	359	21.2	15.9	3.1	no
8/17/2010	2	638	8.26	na	1.8	yes
8/24/2010	1	525	5.15	na	2.4	yes
8/24/2010	2	448	2.28	2.13	2.9	no
8/25/2010	1	394	1.29	1.06	2.9	no
8/25/2010	2	501	0.445	na	2.6	yes

Notes: mg/m^3 means milligrams per cubic meter; na means that the sampling time exceeded eight hours and calculating an eight hour TWA was not applicable. The PEL was adjusted if the sampling time exceeded eight hours.

Respirable Crystalline Silica Results

Table 3 presents the respirable crystalline silica sampling results. The REL was adjusted when the sampling period exceeded 10 hours, while the TLV® was adjusted when the sampling period exceeded 8 hours. The highest recorded results were for Laborer 1 on August 17. His 10-hour TWA results were 8 times the REL and his 8-hour TWA results were 20 times the TLV®. The lowest values found were for Laborer 2 on August 25. His 10 hour TWA was less than the REL and his TWA for the 8 hour 21 minute sample did not exceed the adjusted TLV®. Eight and ten hour TWAs were calculated assuming no further exposure during the unsampled portion of the work day.

Overall, the TWA respirable crystalline silica results ranged from 0.0221mg/m^3 to 0.675 mg/m^3. The data were log-normally distributed. The geometric mean respirable crystalline silica TWA was 0.12 mg/m^3. The geometric median respirable crystalline silica TWA was 0.13 mg/m^3 and the geometric standard deviation was 3.5 mg/m^3.

Table 3 – Respirable Crystalline Silica Results

Date	Laborer	Sampling Time (minutes)	Respirable Crystalline Silica TWA Concentration (mg/m^3)	Respirable Crystalline Silica 10 Hour/8-Hour TWA Concentration (mg/m^3)	NIOSH REL/ACGIH® TLV® (mg/m^3)	Adjusted
8/17/2010	1	359	0.675	0.404/0.505	0.05/0.025	no
8/17/2010	2	638	0.284	na/na	0.04/0.016	yes(both)
8/24/2010	1	525	0.202	0.177/na	0.05/0.022	yes(TLV®)
8/24/2010	2	448	0.0825	0.0616/0.0770	0.05/0.025	no
8/25/2010	1	394	0.0479	0.0315/0.0394	0.05/0.025	no
8/25/2010	2	501	0.0221	0.0185/na	0.05/0.023	yes(TLV®)

Notes: mg/m^3 means milligrams per cubic meter; na means that the sampling time exceeded eight or ten hours and calculating an eight or ten hour TWA was not applicable. The TLV® was adjusted if the sampling time exceeded eight hours. The REL was adjusted if the sampling time exceeded 10 hours.

Weather Monitoring Results

The average wind speed was 6.1 kilometers per hour (kph) (3.8 miles per hour (mph)) on August 17, with an average wind direction of 246°. Weather monitoring began at 7:12 a.m. and ended at 5:40 p.m. On August 24, the average wind speed was 12.7 kph (7.9 mph). The average wind direction was 30° on that day. Readings were collected from 7:18 a.m. to 6:03 p.m. The average wind velocity was 11.1 kph (6.9 mph) on August 25, with an average direction of 342°. Weather data were collected from 7:05 a.m. to 5:35 p.m. on August 25.

Matching the wind speed and direction to the Laborers' sampling periods resulted in the data shown in Table 4. Table 5 presents the wind speed and direction for both Laborers' drilling days (i.e., averaged over their total sampling periods).

Table 4 Wind Speed and Direction by Worker and Sample Period

Date	Laborer	Sample Period	Average Wind Speed (kph)	Average Wind Speed (mph)	Average Wind Direction (degrees)
8/17/2010	1	1	1.3	0.80	78
8/17/2010	1	2	5.8	3.6	265
8/17/2010	1	3	7.4	4.6	262
8/17/2010	2	1	1.3	0.78	81
8/17/2010	2	2	5.1	3.2	270
8/17/2010	2	3	7.7	4.9	277
8/17/2010	2	4	7.1	4.2	213
8/17/2010	2	5	11	7.0	249
8/17/2010	2	6	13	9.2	231
8/24/2010	1	1	8.3	5.2	9
8/24/2010	1	2	12	7.4	40
8/24/2010	1	3	17	10	28
8/24/2010	1	4	15	9.0	47
8/24/2010	2	1	8.5	5.4	14
8/24/2010	2	2	12	7.2	42
8/24/2010	2	3	15	9.1	30
8/24/2010	2	4	17	11	22
8/25/2010	1	1	10	6.3	1.3
8/25/2010	1	2	14	8.5	337
8/25/2010	1	3	26	9.9	327
8/25/2010	2	1	4.9	3.0	336
8/25/2010	2	2	8.8	5.3	359
8/25/2010	2	3	11	6.8	356
8/25/2010	2	4	16	9.8	333

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

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

Date	Laborer	Average Wind Speed (kph)	Average Wind Speed (mph)	Average Wind Direction (degrees)
8/17/2010	1	4.2	2.6	270
8/17/2010	2	6.1	3.8	246
8/24/2010	1	13	7.8	32
8/24/2010	2	12	7.7	28
8/25/2010	1	14	8.6	339
8/25/2010	2	10	6.5	345

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

Productivity Results

The number of holes drilled by Laborer 1 was not recorded for the first two sampling periods on August 17, 2001. He drilled 308 holes during the third sampling period and 462 holes during the fourth sampling period on August 17. On August 24, Laborer 1 drilled 1636 holes. On August 25, he drilled 1406 holes. Laborer 2 drilled a total of approximately 2387 holes on August 17, 1830 holes on August 24, and 2266 holes on August 25. Table 6 provides the number of holes drilled for each sampling period on August 24 and 25, when those data were recorded.

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

Date	Laborer	Sample Period	Holes Drilled
8/24/2010	1	1	363
8/24/2010	1	2	686
8/24/2010	1	3	321
8/24/2010	1	4	266
8/24/2010	2	1	only daily total (1830) recorded
8/24/2010	2	2	only daily total (1830) recorded
8/24/2010	2	3	only daily total (1830) recorded
8/24/2010	2	4	only daily total (1830) recorded
8/25/2010	1	1	367
8/25/2010	1	2	359
8/25/2010	1	3	680
8/25/2010	2	1	539
8/25/2010	2	2	605
8/25/2010	2	3	550
8/25/2010	2	4	572

Data analyses

The data collected on August 24 and 25, 2010 were analyzed using multiple linear regression. The data for August 17 were not included in the analyses because the number of holes drilled was not reliably recorded for both workers on that day. The dependent (exposure) variables were TWA respirable dust concentration and TWA respirable quartz concentration. Since environmental measurements are usually log-normally distributed, the exposure measurements were log-transformed. The independent variables included in the analyses were employee, wind speed, wind direction, number of holes drilled, and an interactive term of wind speed multiplied by wind direction. Stepwise multiple linear regression (forward, backward and max r) was used for the analyses. Only the employee variable was significant at the 95% confidence level. However, since the same workers operated the same drills both days, it was impossible to separate the influence of the tool and the influence of the worker (i.e., work practices) on the exposure outcome. The same analyses were carried out for the respirable dust and crystalline silica results for each sampling period on August 24 and 25, 2010, with the same outcome. Based upon the data collected during this site visit, an exposure model could not be constructed.

Conclusions and Recommendations

Respirable crystalline silica exposures up to eight times the NIOSH REL indicate that steps should be taken to control exposures to acceptable limits. The use of engineering control technology such as dust control systems would be the preferred solution and adhere to the hierarchy of controls. Both E-Z Drill and Minnich offer optional dust control systems that can be retrofitted to older model drills. Those dust control systems, 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 despite losses due to friction, fittings, and hood entry [ACGIH® 2010]. Minnich uses eductors to move the air in their system. E-Z Drill uses pneumatic dust collectors on smaller drill rigs and a pneumatic fan on larger gang drills.

Both manufacturers also sell water spray systems to suppress drilling dust. E-Z Drill uses a water spray that wets the surface of the concrete. Minnich injects water into the hole through the hollow drill steel and an orifice in the bit, replacing the bailing air with water.

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]. The 8-hour TWA exposures measured during this survey did not exceed 10 times the OSHA PEL for respirable dust calculated based upon the quartz content of the samples. The measured 10-hour TWA exposures did not exceed 10 times the NIOSH REL for respirable crystalline silica, either. 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.

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Appendix

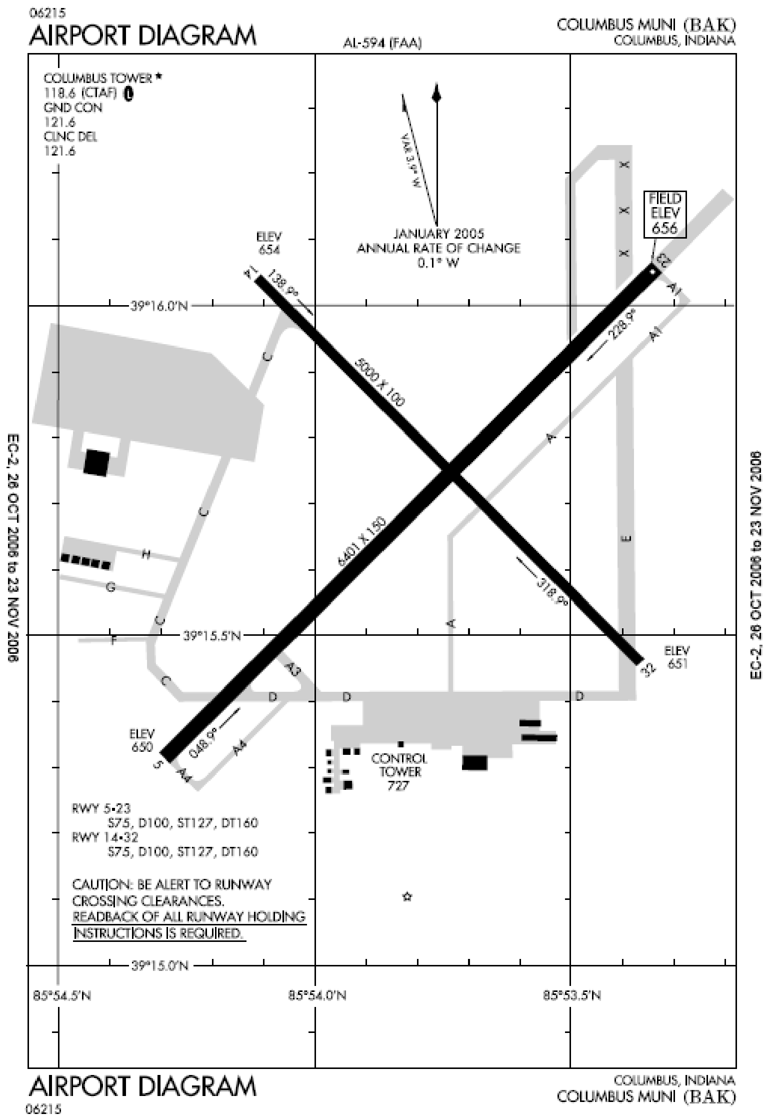

Figure A1 - Airport Diagram. Runway Construction Took Place on Runway 5-23, Below the Intersection with Runway 14-32 [FAA 2010].

Table A1 - Respirable Dust Sampling Results

Date	Laborer	Sampling Period	Duration (min)	Volume (L)	Respirable Particulate (µg/sample)	Respirable Concentration (mg/m^3)
8/17	1	1	120	271	4100	15.1
8/17	1	2	122	275	9000	32.7
8/17	1	3	117	264	4100	15.5
8/17	1	4	>80*	could not determine	3900	could not determine
8/17	2	1	119	267	4800	18.0
8/17	2	2	119	267	3000	11.2
8/17	2	3	121	272	1400	5.15
8/17	2	4	118	265	1500	5.66
8/17	2	5	117	263	920	3.50
8/17	2	6	44	99	210	2.1
8/24	1	1	118	264	3000	11.3
8/24	1	2	166	372	1700	4.57
8/24	1	3	126	282	440	1.56
8/24	1	4	115	258	920	3.57
8/24	2	1	120	266	1700	6.39
8/24	2	2	127	282	420	1.49
8/24	2	3	121	269	(67)	(0.25)
8/24	2	4	80	178	(77)	(0.43)
8/25	1	1	109	246	750	3.05
8/25	1	2	107	242	130	0.537
8/25	1	3	178	402	270	0.672
8/25	2	1	128	285	ND	<0.0993
8/25	2	2	118	263	ND	<0.108
8/25	2	3	122	271	150	0.553
8/25	2	4	133	296	290	0.980

Notes: *The sampling hose was found to be disconnected from the cassette after 28 minutes of sampling, then reconnected and the cassette was used for an additional 80 minutes. Since it could not be determined when the hose was disconnected, this sample was not included in any of the analyses (e.g., TWA calculations, etc.) because the sample volume and concentration could not be determined. min means minutes, L means liters, 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.

Table A2 – Silica Sampling Results

Date	Laborer	Sampling Period	Duration (min)	Volume (L)	Quartz (µg/sample)	Quartz Concentration (mg/m^3)
8/17	1	1	120	271	140	0.517
8/17	1	2	122	275	230	0.836
8/17	1	3	117	264	160	0.606
8/17	1	4	>80*	could not determine	140	could not determine
8/17	2	1	119	267	150	0.562
8/17	2	2	119	267	100	0.375
8/17	2	3	121	272	48	0.18
8/17	2	4	118	265	54	0.20
8/17	2	5	117	263	32	0.12
8/17	2	6	44	99	(14)	(0.14)
8/24	1	1	118	264	120	0.455
8/24	1	2	166	372	61	0.16
8/24	1	3	126	282	(16)	(0.057)
8/24	1	4	115	258	36	0.14
8/24	2	1	120	266	57	0.21
8/24	2	2	127	282	18	0.064
8/24	2	3	121	269	ND	<0.0131
8/24	2	4	80	178	ND	<0.0199
8/25	1	1	109	246	27	0.11
8/25	1	2	107	242	(6.8)	(0.028)
8/25	1	3	178	402	(8.9)	(0.022)
8/25	2	1	128	285	ND	<0.0124
8/25	2	2	118	263	ND	<0.0134
8/25	2	3	122	271	(5.6)	(0.021)
8/25	2	4	133	296	(12)	(0.041)

Notes: *The sampling hose was found to be disconnected from the cassette after 28 minutes of sampling, then reconncted and the cassette was used for an additional 80 minutes. Since it could not be determined when the hose was disconnected, this sample was not included in any of the analyses (e.g., TWA calculations, etc.) because the sample volume and concentration could not be determined. min means minutes, L means liters, 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 quartz concentration, which is noted with a < sign.

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