IN-DEPTH SURVEY: PRELIMINARY EVALUATION OF DUST EMISSIONS CONTROL TECHNOLOGY FOR DOWEL-PIN DRILLING

At

Minnich Manufacturing
Mansfield, OH

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The findings and conclusions in this report are those of the author(s) and do not necessarily reflect the views of the National Institute for Occupational Safety and Health.

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ABSTRACT

This study evaluated the performance of a commercially-available local exhaust ventilation engineering control used to reduce dust emissions from a dowel drilling machine. Compared with the use of no control during dowel drilling in concrete, the control significantly reduced respirable dust concentrations by 89% ($p<0.0001$) and significantly reduced respirable dust particle counts by 50 to 70% ($p<0.0001$). The particle size distribution of the dust emissions probably accounts for this discrepancy. Evaluations were conducted with and without a tent enclosing the dowel drilling machine. Results of the evaluations demonstrate the utility of using an enclosure to isolate a piece of construction equipment from the effects of its environment during a control evaluation. However, the use of this technique means that it would not be appropriate to compare the emissions measurements reported here to any exposure index. Recommendations that are expected to improve the effectiveness of the dust control are provided at the end of the report.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is located in the Centers for Disease Control and Prevention (CDC), part of the Department of Health and Human Services (DHHS). NIOSH was established in 1970 by the Occupational Safety and Health Act, when the Occupational Safety and Health Administration (OSHA) was created concurrently in the Department of Labor (DOL). The OSH Act legislation mandated NIOSH to conduct research and education programs separate from the standard-setting and enforcement functions conducted by OSHA. 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 (DART) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness. Since 1976, EPHB (and its predecessor, the Engineering Control Technology Branch) has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique. The objective of each of these studies has been to evaluate and document control techniques and to determine their effectiveness in reducing potential health hazards in an industry or for a specific process.

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 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 that is capable of entering the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 µm [NIOSH 2002].

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, documenting exposures to an operator and laborer using a backhoe-boom-mounted dowel drilling machine. That evaluation found that the operator's exposures to quartz ranged from less than the limit of detection to 0.11

mg/m^3 8-hr time weighted average (TWA). The laborer's quartz exposure ranged from 0.12 to 1.3 mg/m^3, 8-hr TWA, 26 times the NIOSH Recommended Exposure Limit for quartz (and all forms of crystalline silica) of 0.05 mg/m^3, for up to 10 hours as a TWA.

Dowel drilling machines (or dowel-pin 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 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 9-in (the diameter is determined by the use of cement-based grout or epoxy anchoring formulations), the hole is cleaned with a compressed air nozzle, the anchoring material is placed, and the dowel is installed [FHWA 2006]. This study only evaluated drilling process. Cleaning the hole with compressed air was not part of the evaluation.

In this study, performed at the equipment manufacturer's factory, we sought to quantify the extent to which a local exhaust ventilation system was able to reduce respirable dust emissions from a dowel drilling machine in a controlled setting. The local exhaust ventilation system utilized close-capture hoods (dust collector drill guide assembly) that surrounded the drill steels and bits and were in close contact with the concrete substrate (see Figure 1). The dust was conveyed from the hoods to a dust collection system utilizing flexible corrugated hose. The dust collectors utilized pneumatic eductors to provide suction and filtered the air prior to discharge to the atmosphere.

The NIOSH researchers conducted two days of research during this study. During the first day, an attempt was made to adjust the airflow of the dust control system to determine a minimum effective rate. As the first day's testing progressed, some of the exhaust tubing clogged with settled particulate. Since the point at which the blockage occurred went unnoticed, the NIOSH researchers considered the research conducted that day to be a dry-run for the second day. The methods and results below describe the second day of research.

METHODS

Experimental design

The aim of this study was to estimate the reduction in respirable dust emissions achieved through the use of the local exhaust ventilation system. This reduction was measured by comparing the respirable dust emissions when the system was in operation ("control") with the respirable dust emissions when the system was not in operation ("no-control"). In order to measure this reduction, trials of the dowel drilling machine dust control were conducted in eight sampling rounds consisting of two trials in each sampling round – "control" and "no-control." The order of the trials was randomized within each sampling round. Real-time dust samples were collected during each trial.

Each dowel drilling machine trial consisted of using a five-gang dowel drilling machine (Model A-5SC, Minnich Mfg. Co., Mansfield, OH) to drill four holes in blocks of concrete laid on their long side in the outdoor testing area behind the Minnich Manufacturing facility located in Mansfield, OH (see Figure 2). The dowel drilling machine was placed on top of a 6-foot (ft) by 9¾-ft concrete pad. A row of three solid blocks of 3000 pounds/square-inch (psi) concrete 20-inches (in) wide by 36-in long by 11-in high (Moritz Concrete, Inc., Mansfield, OH) were placed against the front of the concrete pad. The pneumatically-powered dowel drilling machine was maneuvered on the pad in order to drill four new 1⅜-in diameter holes for each trial. The dowel drilling machine was positioned in order to avoid drilling a hole in a joint between the blocks. It was also placed so that none of four close-capture hoods was covering a joint or a portion of an existing hole. The position of the dowel drilling machine was also adjusted in order to place the hoods in contact with the surface of the concrete block. These spacing limitations restricted the study to using four of the five drills at a time. The dowel drilling machine could be driven from side to side (crabbed) and the array of drills raised or lowered as a unit. Each of the drills was capable of being switched on or off independently of the others. The dowel drilling machine and its dust collector were powered by a 750 cfm diesel-powered air compressor (IR 750, Ingersoll-Rand, Mocksville, NC).

In order to conduct the evaluation in a controlled environment, free from the effects of the wind and to minimize interference from diesel exhaust particulate, the dowel drilling machine, slab and blocks were placed inside a tent (10 x 20 Garage - Unicage, Item No. MAC-GAR04, MAC-Automotive, Inc. Laverne, CA) equipped with a roll-up front door that could be closed with two zippers. Polyethylene sheeting (4-mil, Film-Gard, Covalence Plastics, Minneapolis, MN) was duct-taped to the bottom of the side and rear walls to prevent air infiltration and to keep dust from escaping. The bottom edge of the polyethylene sheeting was held to the ground using two lengths of metal chain (⅜-in by 30-ft grade 43 zinc-plated chain, Hi-Test Chain, Crown Bolt, Aliso Viejo, CA) to form a ballast (see Figure 3).

<u>Emissions assessment methods</u>

Respirable dust emission concentrations under the “control” and “no-control” conditions were estimated using Personal Dataram (Model pDR-1000AN, Thermo Electron Corp., Franklin, MA) instruments. The pDR is nephelometer that uses light scattering to produce a measure of dust over a size range of 0.1-10 micrometers (µm) and a concentration range of 0.001 to 400 milligrams of dust per cubic meter of air (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 study, the pDRs were set up to record an average dust concentration every second.

Particle counts of dust emissions were obtained using real-time aerosol spectrometers (model 1.108, versions SS and 8.5, Grimm Technologies, Inc., Douglasville, GA). The Grimm instruments utilize light scattering, where a particle passes through a beam generated by a semiconductor laser, the scattered light is collected by a mirror and transferred to a detector. The intensity of the amplified signal produced by the scattered light and gathered by the detector is proportional to the size of the particle. The signals are counted and classified by size to produce a particle count in each size range. The size ranges are 0.30-0.40 µm, 0.40-0.50 µm, 0.50-0.65

µm, 0.65-0.80 µm, 0.80-1.0 µm, 1.0-1.6 µm, 1.6-2.0 µm, 2.0-3.0 µm, 3.0-4.0 µm, 4.0-5.0 µm, 5.0-7.5 µm, 7.5-10.0 µm, 10.0-15.0 µm, 15.0-20.0 µm, and >20.0 µm. The first twelve size ranges (from 0.30-10 µm) represent respirable particulate. Two of the Grimm instruments were configured to record an average particle count every minute (model 1.108 version 8.5), while four were configured to record an average particle count every six seconds (model 1.108 version SS). Three of the Grimm instruments were selected from those available without regard to the version and used during each trial.

The instruments were placed in tripod-mounted brackets approximately 60-in above grade (either the ground or the concrete pad) to sample at personal breathing zone height (see Figures 4 and 5). The tripods were placed at three locations: in front of the dowel drilling machine, next to the operator's position, and adjacent to the dust collector behind the dowel drilling machine. Reference points on the dowel drilling machine were selected to orient the tripods so that they could be easily repositioned before each trial. The tripod in front of the dowel drilling machine was aligned with the center of the drilling array and placed about 24-inches in front of the dowel drilling machine. The sampler next to the operator's position was aligned with the front bolt securing the control panel cover for the travel valve and placed about 32-in to the left of the centerline of the overall dowel drilling machine. The sampler behind the dowel drilling machine was aligned with center of the middle dust collector and placed about 30-in to the rear of the dowel drilling machine.

<u>Test procedure</u>

For a given trial, the drills were positioned on the blocks. The NIOSH researchers started the data collection period with each of the samplers and recorded the sampling start time. The NIOSH researchers lowered the tent door and closed its zippers. A Minnich supervisor started the dowel drilling machine from outside the tent using a remote control. The NIOSH researchers recorded the drill start time. The drills shut off automatically and withdrew from the holes after reaching a pre-set depth of 9 inches. The NIOSH researchers recorded the last drill stop time. The NIOSH researchers waited five minutes after the last drill stopped. They donned half-facepiece dual-cartridge respirators with HEPA filters, unzipped and raised the tent door, entered the tent and stopped the data collection period for each of the samplers. The NIOSH researchers recorded the sampling stop time. Next, they raised the tent flap in the right rear corner and installed a 30-in fan (Maxx Air High Velocity, Ventamatic, Ltd., Mineral Wells, TX) to ventilate the tent. They continued to supply ambient air to the tent using the fan until the dust concentration fell below 0.05 mg/m^3 (equal to the outdoor background respirable particulate concentration) as indicated by a handheld pDR temporarily located on top of the dowel drilling machine near the operator's controls. Once the concentration had dropped to this level, Minnich personnel entered the tent and repositioned the dowel drilling machine for the next test. The NIOSH researchers then moved the samplers to the desired positions relative to the dowel drilling machine, removed the fan and re-sealed the tent flap, and repeated the process. Seven rounds of sampling were performed in this manner. An eighth sampling round was performed with no tent in place to determine if there was a difference between emissions measured under ambient conditions and those measured using the tent.

Statistical methods

The “control” and “no-control” order in which the tests were conducted was randomized to account for any bias due to measurement order. In addition to randomizing the “control” and “no-control” order of the tests, the instruments were rotated among the three sampling positions at random. This was done to account for any instrument bias in the measurements.

SAS version 9.1 statistical software (SAS Institute Inc., Cary, NC) was used to analyze the data. Collecting data in three locations during 8 sampling rounds of “control” and “no-control” conditions using two types of instrument resulted in 96 data sets. Eighty-four of those sets represented sampling rounds 1-7, where the tent was used. An additional 12 data sets represented sampling round 8, where the tent was not used. The result was 42 sets of particle count data and 42 sets of dust concentration data collected using the tent, and 6 sets of each type of data collected without the tent.

The first step in analyzing the data was to establish the limits for the data sets to be analyzed. During each sampling event, the real-time instruments used to measure the dust in this study recorded baseline (or background) dust data during the interval between when the data collection was started and when the drill was started during each testing period. A typical plot of the data (Figure 6) shows that this baseline level is followed by a rapid increase in the instrument’s response (corresponding to a point in time when dust from the drills first reached the sensor) and then a relatively stable period of decline until data collection was terminated by the investigators. The tasks involved in establishing the limits for the data (trimming the data) involved removing the baseline and rapidly increasing periods from the data sets to be analyzed and determining where the sampling period ended. This task was complicated by the fact that the internal clocks in the pDR instruments were not synchronized with the Grimm instruments. The Grimm instruments were synchronized with the watch used to record the times noted above.

For the pDR instrument data, the data from sampling rounds 1-7 were first examined using an algorithm that looked for the first increase in consecutive values of 2 mg/m^3 beginning with the first logged value (the instrument start time). The result of applying that rule corresponded very closely to the beginning of the rapid increase from the baseline response (the recorded drill start time). One minute was added to that time. That minute accounted for the transition time from baseline to a stable response. Four minutes were added to that time to determine the end point for the analyses. The data points recorded during those four minutes were included in the analyses.

The data from the Grimm particle counters was first treated by adding the count data for the particles size ranges 10 µm and less (0.30-0.40 µm, 0.40-0.50 µm, 0.50-0.65 µm, 0.65-0.80 µm, 0.80-1.0 µm, 1.0-1.6 µm, 1.6-2.0 µm, 2.0-3.0 µm, 3.0-4.0 µm, 4.0-5.0 µm, 5.0-7.5 µm, and 7.5-10.0 µm) to produce a respirable dust count for each logging interval (either 6 seconds or 1 minute). Next, one minute was added to the drill start time to account for the transition time from baseline to a stable response. This time marked the beginning of the interval for the data to be analyzed. Four minutes were added to that time to determine the end time of the interval. All of the data points in that four minute interval were included in the analyses.

Once the data sets were determined for sampling rounds 1-7, the arithmetic means were calculated for each data set. Those arithmetic means were used as the response value for that set. The logs of the arithmetic means were taken and used for mixed modeling for sampling rounds 1-7 and to estimate the reduction achieved by the use of the control. The geometric mean of the response value for each position (rear, operator, and front) for both the "control" and "no-control" conditions was then calculated. The percent reduction achieved by the dust control was calculated using the geometric mean of the "control" and "no-control" means and the equation

$$\%\ \text{Reduction} = 100 \text{ x } \left[1 - \left(\text{geometric mean (control means)} \div \text{geometric mean (no - control means)}\right)\right] \cdot$$

A mixed model was used to calculate an estimate of the lower limit of the reduction using the log-transformed means for both the particle counts and the dust concentrations for sampling rounds 1-7 only.

For the data collected in sampling round 8, the same rule was applied to both the pDR instrument data and Grimm instrument data. All of the data between one and four minutes after the drill start time were included in those analyses. The arithmetic mean was calculated for that interval for all of the sampling round 8 data. The geometric means of the "control" and "no-control" means were used to calculate the reduction achieved through the use of the control using the equation above.

<u>Description of tools and controls</u>

The dowel drilling machine tested was a Minnich model A-5SC five drill self-propelled on-slab unit, used with "H" thread steels and bits. The drill rotates and hammers the steel and bit to produce the desired hole in the concrete. Each of the steels and bits was surrounded by a close-capture hood at the work surface (Figure 1). Each hood take-off was attached to a length of 2-in diameter corrugated flexible hose (the interior 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 unit tested, hoods 1 and 2 were attached to the dust collector on the left, hood 3 was connected to the center dust collector, and hoods 4 and 5 were served by the dust collector on the right. Suction is provided by a pneumatic transfer pump. There are two each on the left and right dust collector and one on the center dust collector. A 2-in pleated Merv 13 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 dust collected on the filter falls into a catch can at the bottom of the dust collector for disposal. Minnich technicians adjusted the compressed air supply to supply 50 cfm of exhaust air to each transfer pump. The air mufflers on the drills were rotated 90º to avoid blowing air onto settled dust on the ground in front of the blocks.

RESULTS AND DISCUSSION

It is important to remember that this evaluation was designed to measure reductions in emissions under controlled conditions. These results should not be interpreted to represent potential exposures to drill operators. Table 1 reports the reductions in respirable dust mass concentrations (pDR data) achieved at all three positions through the use of the dust collection system on the machine for sampling rounds 1-7, when the tent was used to enclose the drill and samplers. Those results indicate that the dust collection system was able to reduce respirable dust mass concentrations by 89% at all three sampling positions. The reductions were significant ($p<0.0001$) based on an F-test of the mixed model. Table 2 provides the geometric mean respirable dust mass concentrations used for the comparison. For both the "control" and "no-control" conditions, the values increased from the rear sampling location behind the dust collectors to the front sampling location, nearest the drills. For the "control" condition, the geometric mean respirable dust mass concentration ranged from 13.5 mg/m^3 at the rear of the dowel drilling machine to 20.4 mg/m^3 at the front. For the "no-control" condition, the geometric mean respirable dust mass concentration ranged from 125 mg/m^3 at the rear to 195 mg/m^3 at the front of the dowel drilling machine.

Table 3 shows the reductions in respirable dust particle counts (Grimm data) that resulted from the use of the dust control during sampling rounds 1-7, when the tent was used. The reductions ranged from 50 to 70%, with the highest reduction noted at the front of the machine and the lowest at the operator position. The reductions were significant ($p<0.0001$) based on an F-test of the mixed model. The discrepancy between the reductions in respirable mass and respirable count measures may be due to the particle size distribution of the dust. Figure 7 shows the average particle count for each size range included in the respirable count for the sample collected at the operator's position during sampling round 2 when the control was turned on. The largest number of particles is indeed in the smallest size range, 0.30 to 0.40 µm in diameter. Table 4 lists the geometric mean particle counts used to compute the reduction achieved in sampling rounds 1-7. The geometric mean particle counts at the rear and operator positions were very close during the "no-control" condition, while the particle count at the front was lower. The lowest geometric mean particle count was found in the front during the "control" condition.

Tables 5 and 6 provide an estimate of the lower confidence limit for the reduction achieved based on the mixed model. Table 5 shows that the model indicates that for the dust mass concentration data for sampling rounds 1-7, the control is able to achieve at least an 86% reduction at all three positions. Table 6 reports that modeling indicates that the minimum control achievable based on the particle count data ranged from 36% at the operator position to 53% at the rear of the machine.

Tables 7 and 8 provide the reduction ratios achieved during sampling round 8 when no tent was used and show the effect of environmental variables such as wind direction and velocity on demonstrating the effectiveness of the dust control. Overall reductions in dust concentrations and dust counts were greater when the tent was used.

Summary statistics for sampling rounds 1-7 for the respirable dust concentration and respirable dust count results are presented in Tables 9 and 10. Table 9 shows that during sampling rounds 1-7, the highest average dust mass concentrations were typically recorded at the front of the unit, while the lowest were generally recorded at the rear of the unit, with a few exceptions, notably during sampling round 7. One would expect the highest dust concentrations to be found nearest the drills; the explanation for the change in the pattern in sampling round 7 is not clear.

Table 10 reveals a different pattern for the particle count results. During the “control” tests, the highest average particle counts were generally recorded at the operator’s position (except for sampling round 7), while during the “no-control” tests, the highest average particle counts were recorded at the rear of the machine during sampling rounds 1-4, and at the front of the dowel drill during sampling rounds 5-7. The reasons for those patterns are not immediately apparent based on observations made during the tests. The patterns observed during the “control” tests may be an artifact of the use of the tent, or the fact that the tent was closer to the back of the drill than the front. Reviewing the standard deviations shows that the means may not be significantly different. This experiment was designed to examine the effectiveness of the control; a different experimental design could better address emissions sources.

Tables 11 and 12 present the summary statistics for sampling round 8. Table 11 shows that dust concentrations during the “control” tests were not very different at the three positions, but were slightly higher at the operator position; during the “no-control” test, the dust concentration was lowest at the rear position, and similar at the front and operator positions. Table 12 shows that the highest particle count was observed at the front during the “no-control” condition and at operator position during the “control” condition, but the standard deviations are so large, that some readings would overlap.

Finally, reviewing Figure 6 suggests that the dust concentration rises as the drill penetrates the concrete surface and then falls as the drill depth increases. The drilled hole itself probably acts as a dust control device. If this pattern can be confirmed by subsequent tests, it may be possible to vary the exhaust flow rate over the course of the drilling sequence, with a lower flow rate required at the end of the event.

CONCLUSIONS AND RECOMMENDATIONS

Tests conducted using the tent in sampling rounds 1-7 demonstrated that the control technology is able to reduce respirable dust concentrations by 89% overall, showing very good emissions control. Respirable dust count data showed that the control was able to reduce dust emissions from 50 to 70%. The respirable dust count data revealed slightly less effective emissions control, probably due to the particle size distribution of the drilling dust emissions. An analogy may be helpful in explaining this discrepancy. A pound of cherries represents the same mass as a pound of apples, but contains many more pieces of fruit per pound. Similarly, a mass-based dust measurement is weighted toward the larger particles, even though they may be fewer in number in a given sample.

The tests also showed the utility of using a tent to isolate the drilling machine from the effects of the environment during the evaluation. The use of enclosures to evaluate tool emissions is not without precedent. Beamer et al. [2005] and Glinsky [2002] have used ventilated enclosures to evaluate tool emissions from masonry saws and angle grinders. Unlike this evaluation, those studies used a fan to move filtered air past the tool and carry the emissions past a sampler in a duct downstream of the tool. This method has been codified in a European Standard [CEN 2006]. This tool was thought to be too large to employ that approach in a preliminary evaluation like this one. That approach could be considered for any subsequent studies. The particle size distribution suggests that future evaluations could also determine whether dust particles are bypassing the filters in the dust collectors. Future evaluations could also address whether a lower exhaust flow rate would be at least as effective as that utilized here (different pneumatic transfer pumps may be required). Worker exposures associated with the use of the control should also be evaluated. The following recommendations are presented based upon the results of this study and observations made during the study.

- Consider using rigid, smooth pipe or tubing in place of as much of the length of the flexible corrugated dust-collection tubing as possible to minimize friction loss in the system. Alternatively, a flexible hose with a smooth interior could be used in place of the current corrugated hose (e.g., a woven hose). To reduce the potential of clogging due to particle fallout, these ducts should be sized to ensure a minimum duct transport velocity of 4000 feet per minute. Provide a clean-out in each pipe or tube. The material selected should be durable enough to withstand the abrasive nature of concrete dust.

- Consider installing a pressure gauge across each filter in the dust collectors to provide the drill operator with information needed to determine when to clean or change the filter, instead of relying upon indicators such as visible dust emissions. The filter manufacturer should be able to provide the reference data needed to provide this information.

- Consider installing static pressure taps near the duct connection to each hood that can be connected to vacuum gauges on the operator's instrument panel. The hood static pressure can be used to determine if the dust collecting system is working properly. Measuring the hood static pressure when the system is working as designed can provide the baseline value for future comparison.

- Consider extending the height of the discharge stack exiting the dust collector. As shown in the particle size distribution, many of the generated aerosols were in size ranges smaller than the measured filtration efficiency performance of the dust collector. A higher exhaust stack would allow these particles to be released higher above the breathing zone where they would have a greater likelihood for dispersion within prevailing winds as opposed to remaining within the vicinity of the dowel drilling machine. If desired, NIOSH can provide more detailed guidance on how to implement these recommendations**.**

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Table 1: Geometric Mean Reduction Ratios
Respirable Dust Concentration Data (mg/m^3), Sampling Rounds 1-7

Position	Geometric Mean of "Control" Means	Geometric Mean of "No-Control" Means	Percent Reduction
Rear	13.5	125	89.2
Operator	18.3	169	89.1
Front	20.4	195	89.5

Table 2: Sampling Rounds 1-7 Geometric Mean by Position and Condition
Respirable Dust Concentration Data (mg/m^3)
Geometric Mean of Means Based on Mean log (Concentration)

Position	Condition	Number of Means	Geometric Mean of the Means (mg/m^3)
Rear	"Control"	7	13.5
Rear	"No-Control"	7	125
Operator	"Control"	7	18.3
Operator	"No-Control"	7	169
Front	"Control"	7	20.4
Front	"No-Control"	7	195

Table 3: Geometric Mean Reduction Ratios
Respirable Dust Count Data (particles/L), Sampling Rounds 1-7

Position	Geometric Mean of "Control" Means	Geometric Mean of "No-Control" Means	Percent Reduction
Rear	7678818	21188870	63.8
Operator	10641553	21404294	50.3
Front	5033484	16540633	69.6

Table 4: Sampling Rounds 1-7 Geometric Mean by Position and Condition
Respirable Dust Count Data (particles/L)
Geometric Mean of Means Based on Mean log (Count)

Position	Condition	Number of Means	Geometric Mean of the Means (particles/L)
Rear	“Control”	7	7678818
Rear	“No-Control”	7	21188870
Operator	“Control”	7	10641553
Operator	“No-Control”	7	21404294
Front	“Control”	7	5033484
Front	“No-Control”	7	16540633

Table 5: Estimated Lower 5% Reduction Limit for Sampling Rounds 1-7 Based on Mixed Modeling of Dust Concentration Data
Individually Corrected for Lower 5% Value

Position	Estimate	Standard Error	Degrees of Freedom	t Value	Probability	Lower 5% Reduction Limit
Rear	-2.2249	0.1380	9.79	-16.13	<0.0001	86.1%
Operator	-2.2187	0.1380	9.79	-16.08	<0.0001	86.0%
Front	-2.2580	0.1380	9.79	-16.37	<0.0001	86.5%

Table 6: Estimated Lower 5% Reduction Limit for Sampling Rounds 1-7 Based on Mixed Modeling of Dust Count Data
Individually Corrected for Lower 5% Value

Position	Estimate	Standard Error	Degrees of Freedom	t Value	Probability	Lower Reduction Limit
Rear	-1.0150	0.1467	16.8	-6.92	<0.0001	53.2%
Operator	-0.6988	0.1467	16.8	-4.76	0.0002	35.8%
Front	-1.1897	0.1467	16.8	-8.11	<0.0001	60.7%

Table 7: Geometric Mean Reduction Ratios
Respirable Dust Concentration Data (mg/m^3), Sampling Round 8

Position	Geometric Mean "Control"	Geometric Mean "No-Control"	Percent Reduction
Rear	0.108	0.226	52.0
Operator	0.0677	0.342	80.2
Front	0.0789	0.324	75.7

Table 8: Geometric Mean Reduction Ratios
Respirable Dust Count Data (particles/L), Sampling Round 8

Position	Geometric Mean "Control"	Geometric Mean "No-Control"	Percent Reduction
Rear	37962	50995	25.6
Operator	57343	88029	34.9
Front	42063	104430	59.7

Table 9: Summary Statistics, Respirable Dust Concentration Data (mg/m^3), Sampling Rounds 1-7

Round	Condition	Position	Number of Observations	Minimum	Maximum	Arithmetic Mean	Standard Deviation
1	“Control”	rear	241	8.1	27.1	16.2	5.28
		operator	241	10.1	26	16.9	4.02
		front	241	10.1	37.8	20.5	5.7
	“No-Control”	rear	241	57.8	210.4	111.3	34.39
		operator	241	56.7	187.7	100.1	25.69
		front	241	53.6	307.4	147.8	52
2	“Control”	rear	241	11.5	53.9	23.6	8.79
		operator	241	9.7	47.4	22.8	7.58
		front	241	12.8	81.7	34	16.13
	“No-Control”	rear	241	93.5	351.3	183.9	48.12
		operator	241	68.7	393.3	177.5	79.75
		front	241	105	406	234.2	80.31
3	“Control”	rear	241	8.8	28.1	16.3	4.02
		operator	241	13	45.8	25.9	7.03
		front	241	9.2	51.3	25.9	9.24
	“No-Control”	rear	241	67.6	155.6	97.6	18.49
		operator	241	80.1	224.4	145.4	30.17
		front	241	84.3	246.6	156.6	40.12
4	“Control”	rear	241	4.1	16.3	8.5	2.6
		operator	241	5.9	23.8	12.3	4.07
		front	241	4.2	27	11.4	5.63
	“No-Control”	rear	241	70.6	180.2	111.5	21.6
		operator	241	120.9	383.6	203.1	59.88
		front	241	85.8	371.5	196.1	71.01
5	“Control”	rear	241	5.5	16.4	9.7	2.6
		operator	241	9.3	25.8	16	3.48
		front	241	11.9	36.5	20.9	6.29
	“No-Control”	rear	241	82.2	192.2	139.6	22.28
		operator	241	114.9	406.4	225.2	66.54
		front	241	178	405.9	306.6	67.7
6	“Control”	rear	241	7.5	21.7	11.4	2.82
		operator	241	9.1	39.7	20	6.17
		front	241	17.2	69	30	9.14
	“No-Control”	rear	241	64.9	224.1	126.4	31.83
		operator	241	105.3	362.1	208.1	56.37
		front	241	159	405.9	296.5	78.56
7	“Control”	rear	241	7.6	25.1	14	4.02
		operator	241	9.4	26.8	17.8	4.29
		front	241	6.2	17.1	11.2	2.88
	“No-Control”	rear	241	73.3	230.5	122.8	37.33
		operator	241	93.6	265.8	158.3	43.91
		front	241	68.6	165.8	109.8	24.09

Table 10: Summary Statistics, Respirable Dust Count Data (particles/L), Sampling Rounds 1-7

Round	Condition	Position	Number of Observations	Minimum	Maximum	Arithmetic Mean	Standard Deviation
1	“Control”	rear	40	7532980	10244241	8800442	867910.9
		operator	4	12373834	15671508	14028165	1446538.6
		front	4	2624102	3102781	2853868	204898.3
	“No-Control”	rear	40	11623224	18025273	16963336	1482866.9
		operator	4	16686974	16737079	16712860	22858
		front	4	4428891	5945390	5379039	683578.4
2	“Control”	rear	40	8474410	10059810	9121312	465451.3
		operator	4	13627706	16763638	15291905	1369033.6
		front	4	3514635	4193938	3760897	318974.7
	“No-Control”	rear	40	22942633	26349212	25031851	1177971.9
		operator	4	16665129	16730149	16696278	27539.8
		front	4	9977126	12608720	10801176	1240103.8
3	“Control”	rear	40	8592529	9665267	9285827	336972.6
		operator	4	12713031	16536706	14698264	1612162.1
		front	4	3888271	4938733	4388837	482096.7
	“No-Control”	rear	40	12762864	28223968	24859139	3071448.7
		operator	4	16686745	16733996	16710918	20164.1
		front	4	8229233	13092880	11300919	2175976.2
4	“Control”	rear	40	5865773	7584658	6655958	489709.8
		operator	4	7425426	11465704	9427618	1905508.3
		front	4	2970362	4443341	3548537	649229.7
	“No-Control”	rear	40	22495447	25602221	24630592	721925
		operator	4	16665101	16731016	16700811	27327.8
		front	4	12770976	16625942	14952473	1954776
5	“Control”	rear	40	6324135	7844647	7299164	456407.3
		operator	40	6570164	9565819	8374768	804831.3
		front	40	6177475	9016675	7609260	944453.2
	“No-Control”	rear	40	20953130	22788090	21925056	538470.2
		operator	40	29828269	35084582	32720522	1796050.7
		front	40	25947561	37141301	34822865	2161494.9
6	“Control”	rear	36	6331409	7721743	6984328	382898.2
		operator	36	7189106	9068265	8199683	491158.8
		front	31	7108383	9020677	8211137	621671.5
	“No-Control”	rear	40	17267666	22022274	20459790	1561448.9
		operator	40	25872170	33698783	30571371	2554991.7
		front	40	29437361	37376248	33781336	2426588.8
7	“Control”	rear	40	4563997	7710899	6224004	894130.4
		operator	40	5909839	9174222	7570676	1148890.8
		front	40	6206463	8985551	7838102	921848.7
	“No-Control”	rear	40	14320063	18260899	16441731	1226208.4
		operator	40	23812373	29251999	26421831	1836423.3
		front	40	25736539	32710817	29330608	2078010.5

Table 11: Summary Statistics, Respirable Dust Concentration Data (mg/m^3), Sampling Round 8

Condition	Position	Number of Observations	Minimum	Maximum	Arithmetic Mean	Standard Deviation
“Control”	Rear	137	0.0960	0.1340	0.1085	0.0065
“No-Control”	Rear	102	0.1000	2.0830	0.3440	0.3758
“Control”	Operator	157	0.0290	1.7190	0.1430	0.2774
“No-Control”	Operator	115	0.0190	3.4600	0.7619	0.8221
“Control”	Front	161	0.0500	0.8990	0.1096	0.1500
“No-Control”	Front	150	0.0590	13.7500	0.8018	1.6013

Table 12: Summary Statistics, Respirable Dust Count Data (particles/L), Sampling Round 8

Condition	Position	Number of Observations	Minimum	Maximum	Arithmetic Mean	Standard Deviation
“Control”	Rear	24	34745.0	39537.0	37992.84	1541.89
“No-Control”	Rear	44	33270.0	157008.0	60860.78	43206.49
“Control”	Operator	29	35330.0	129801.6	65147.11	34743.01
“No-Control”	Operator	44	34230.0	505704.0	147670.66	157955.77
“Control”	Front	24	28533.4	60192.0	43770.95	12574.18
“No-Control”	Front	25	33580.0	776828.0	244464.62	287248.71

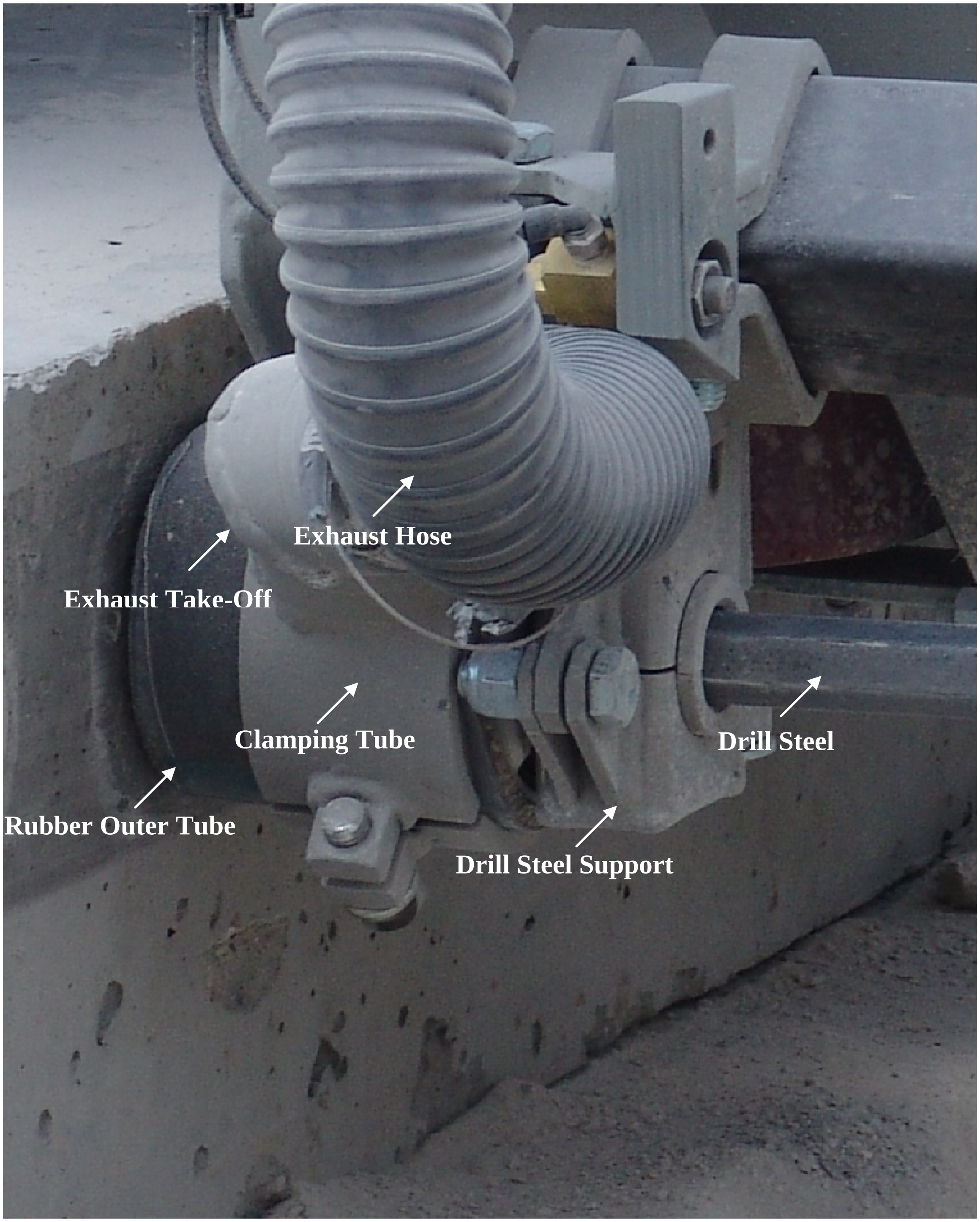

Figure 1: Close Capture Hood

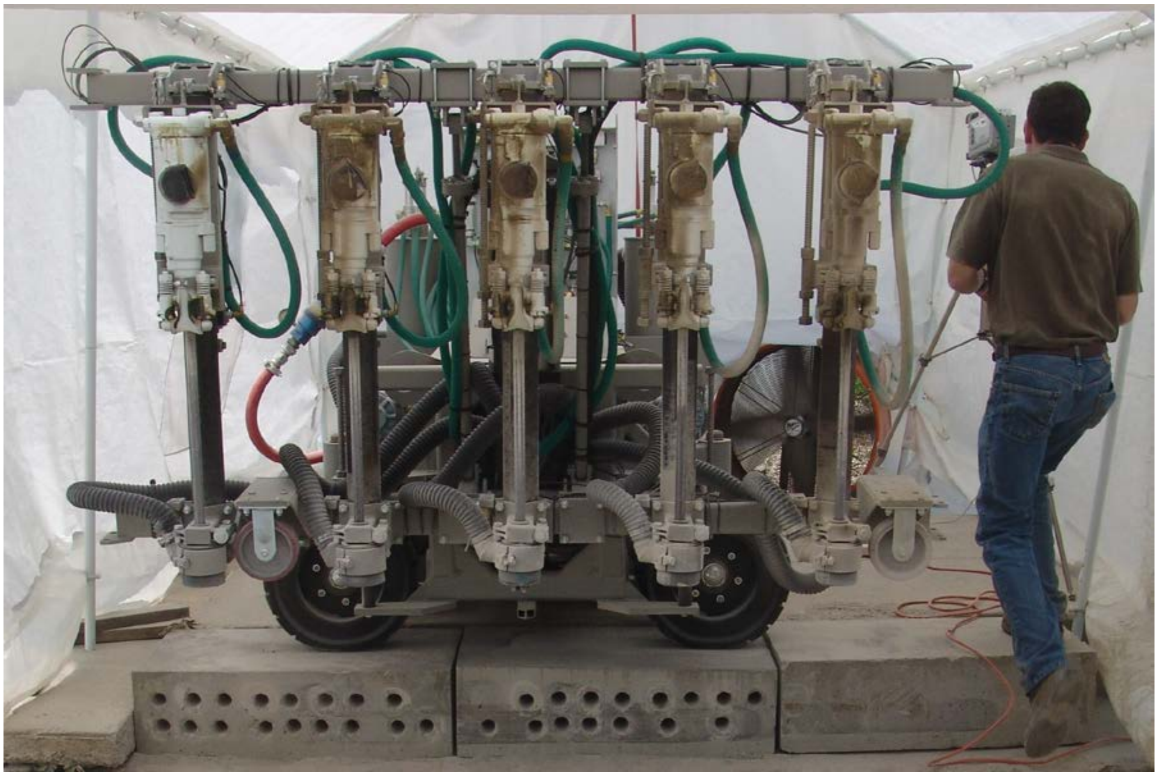

Figure 2: Arrangement of Slab and Blocks

Figure 3: Chain and Sheeting Hold Tent to Ground. Note the Remote Starter Switch.

Figure 4: Sampling Instruments were Placed on Tripods at Breathing Zone Height. This photograph shows the front (top) and operator (left) sampling positions.

Figure 5: Sampling Instruments were Placed at Three Locations. The operator’s platform is at the lower left of the photograph. The dust collectors are in the center of the photograph. the rear sampling position is at the right. The operator stands on the platform while driving the dowel drilling machine. Because the drills stop at a pre-set depth, the operator can start the drills and step away from the dust cloud.

Figure 6: Typical Respirable Dust Concentration Results, Control Condition. The graph illustrates the lag between sampler start, drill start, and the rapid increase in concentration.

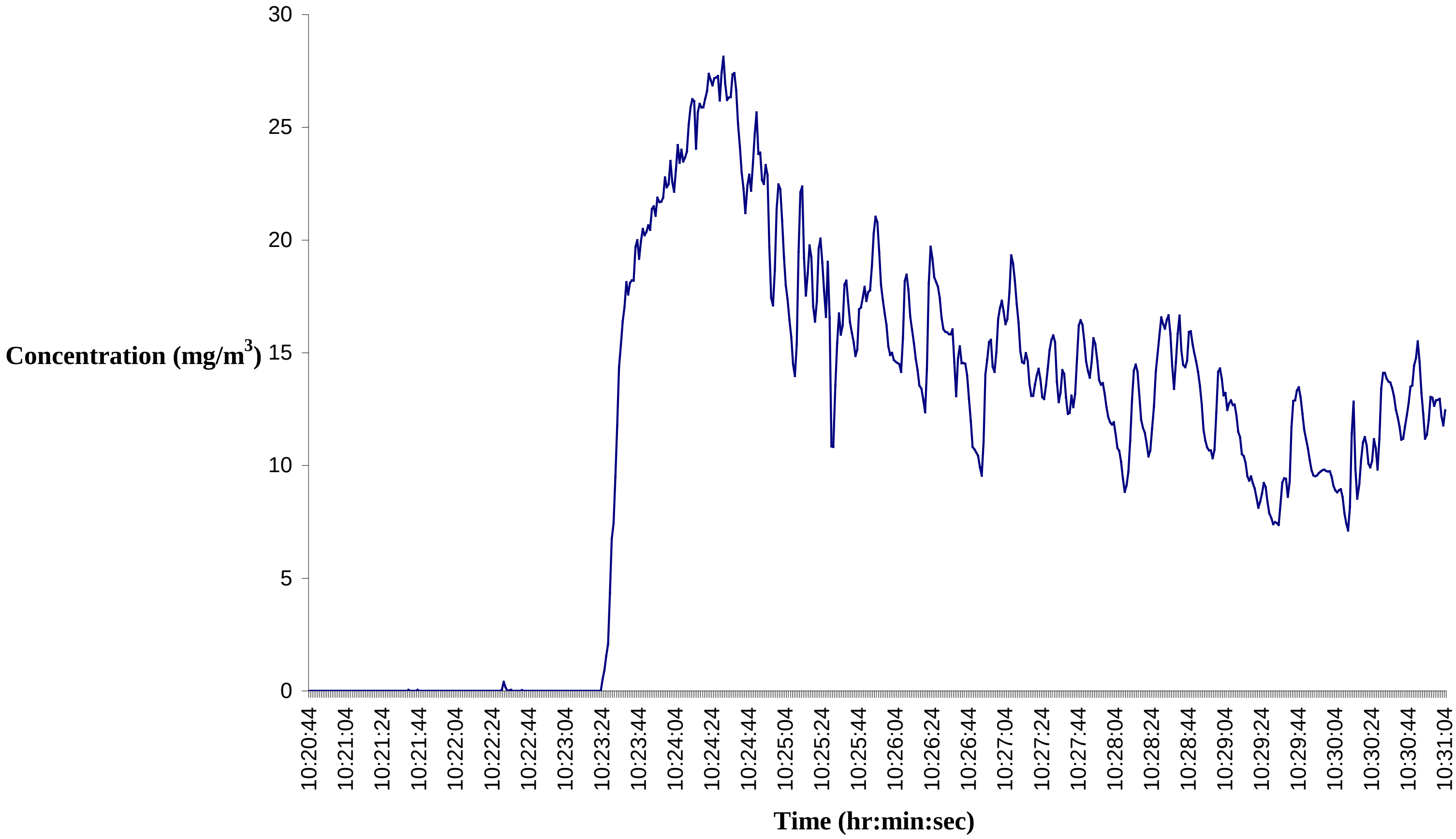

Figure 7: Particle Size Distribution, Round 2, Control, Operator Position