CONTROL TECHNOLOGY FOR READY-MIX TRUCK DRUM CLEANING:

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Plant Surveyed:	Hilltop Basic Resources Cincinnati, Ohio
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Survey Dates:	January 14, 1999 to February 12, 1999
Employer Representative Contacted:	Richard E. Martin Manager, Environmental Mine Safety
Employee Representatives Contacted:	None

I. INTRODUCTION

A NIOSH research study was conducted to evaluate worker exposures to respirable crystalline silica during interior cleaning of ready-mix concrete truck drums. The cleaning of ready-mix drum interiors becomes necessary as the drum interior becomes coated with hardened concrete. During truck maintenance activities workers are required to enter the interior of the cement-mixer drum (a confined space) to remove the hardened concrete. The workers utilize a jackhammer to break the hardened concrete.

The study was conducted at a ready-mix concrete plant with a fleet of 27 ready-mix trucks. The drum cleaning operation is conducted on an annual basis, during the winter construction slowdown. For this study, NIOSH personnel developed and field tested engineering controls designed to capture or suppress silica-containing dusts that are generated during drum cleaning operations, thereby reducing employee exposures. The controls developed included a local exhaust ventilation (LEV) system and water-spray dust suppressant controls for the jackhammer, and general exhaust ventilation (GEV) system for removal of dust from the mixing drum. During this study only the LEV and GEV systems were field tested. The water-spray system was not tested due to reluctance and objections of the company and plant personnel to using water, which they felt may freeze or result in a slipping hazard. The LEV system was designed to be attached to the jackhammer to remove the generated dust at the jackhammer blade. The GEV system was designed to fit over the drum discharge outlet and remove suspended dust from the drum interior.

Four control combinations (no controls, LEV, GEV, and LEV/GEV combined) were evaluated to determine how effective the two control designs, and their combination, were at reducing worker exposures during concrete removal operations. To evaluate the effectiveness of the designed controls, personal breathing zone air samples were collected on employees entering the drum interior. Additionally, video exposure monitoring was conducted utilizing a real time monitor which was synchronized with a video recorder.

II. READY-MIX CONCRETE INDUSTRY AND COMPANY BACKGROUND

This study was conducted at a ready-mix concrete plant that operates a fleet of 27 rear discharge, ready-mix concrete trucks. Ready-mix concrete trucks are equipped with a revolving mixing drum mounted on the truck chassis. The truck is also equipped with a pressurized water tank and hose for removal of spillage by rinsing or spraying the truck with water after each delivery. During loading, transport to the construction site, and delivery the mixing drum is rotated to prevent hardening of concrete within the drum interior. After the contents of the drum are emptied at the construction site, the driver is responsible for rinsing the truck exterior and accessible portions of the mixing drum interior to prevent the buildup of hardened concrete. Despite the best efforts of the drivers, over time the drum interior becomes coated with hardened concrete, necessitating the cleaning operation.

At this facility the cleaning operation is normally scheduled once per calendar year during the winter construction slow down. Two ready-mix drivers volunteer and are trained to conduct the cleaning operation. Because the truck and drum have the potential to be energized and the drum interior is considered to be a confined space, the training includes lockout/tag out and confined space entry procedures. Generally, two trucks are scheduled for cleaning each day. The two employees assigned to the cleaning operation work on a buddy system and enter the drum interior on an alternating basis. The employee entering the drum interior uses a jackhammer to break the hardened concrete and wears a half-face disposable dust mask (3M Model N95 8210), ear plugs plus ear muffs, hard hat, safety boots, and safety glasses. Examples of good work practices and the use of protective equipment were also documented.

Prior to drum entry the two employees are required to follow a safety check list that was developed specifically for the drum cleaning operation. The list includes lockout/tag out and confined space entry procedures.

III. HEALTH HAZARD ANALYSIS

OVERVIEW OF SILICA HEALTH EFFECTS

Silica use is widespread in industry in the United States. Silica exposures have been identified in at least 47 different four-digit SIC codes. These SIC codes contain more than 230,000 establishments employing more than 3.5 million workers. The current OSHA Permissible Exposure Limit (PEL) for respirable dust containing crystalline silica is calculated from the following formula:

$$\text{Respirable PEL} = \frac{10}{(\%\ \text{Silica}) + 2}$$

For example, if the percentage of crystalline silica in the collected dust were 0%, then the respirable PEL would be 5.0 mg/m^3. If the percentage of crystalline silica in the collected dust were 100%, then the respirable PEL would be 0.1 mg/m^3. The current NIOSH Recommended Exposure Limit (REL) for quartz is 0.05 mg/m^3; the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Value (TLV®) is also, 0.05 mg/m^3.

IV. STUDY METHODS

This field study was conducted in accordance with 42 CFR 85a, the NIOSH regulations governing the investigation of places of employment. Because the goal of this study was to assess the effects of engineering controls and work practices on crystalline silica exposures, samplers were placed outside of the respiratory protective equipment worn by the worker.

EQUIPMENT DESIGN

The NIOSH researchers designed engineering controls to reduce or capture airborne dust generated during the breaking and subsequent removal of cured concrete from the drum interior. To design a LEV control for the jackhammer, a duplicate of the jackhammer used by the company was purchased from a local vendor, along with compressor fittings, air hoses, and other numerous small parts needed to retrofit the jackhammer. A sheet metal and rubber shroud with a 1 ½" diameter opening to connect to a vacuum hose was fitted to the hammer. To collect the dusts generated, an industrial vacuum cleaner, filters, hose, and other necessary parts were purchased.

The GEV system was designed to collect dust generated during the operation in the drum interior. The parts of the GEV system included a vinyl coated tarp to fit snugly over the concrete drum discharge opening, flexible ducting, a fan, and dust collection bag. A sheet metal flange was fitted in the center of the vinyl tarp and riveted in place. The vinyl tarp was fitted over the concrete drum discharge chute and held in place with clamps and rope. A flexible 6" diameter duct was attached to the tarp. A fan suitable for exhausting air from the drum interior and a dust collection bag was placed on the exhaust end of the fan to prevent dust from being expelled into the general environment.

For a water spray application, a valve block and a positioning hose with nozzle was fabricated, assembled and fitted on the prototype. The nozzle is designed to spray a water mist at the jackhammer blade for dust suppression.

During the study described here only the local exhaust ventilation and general exhaust ventilation systems were field tested. The water-spray system was not tested due to reluctance and objections of the company and plant personnel to using water.

STUDY DESIGN

This study was conducted to determine if the controls designed by the NIOSH researchers can effectively reduce the dust levels generated, and thus the resulting worker exposure concentrations, during the removal of concrete using a jackhammer equipped with LEV and a GEV system designed to exhaust suspended dusts from the drum interior.

To evaluate the effectiveness of the control designs, four sampling scenarios were set up to compare employee personal breathing-zone (PBZ) air concentrations. The four sampling scenarios included: 1) no controls - using the company's 25 or 30 pound jackhammer and 20 inch box fan in hopper and placed in the concrete discharge chute; 2) LEV system - using NIOSH 25 pound jackhammer equipped with LEV. LEV consists of a vacuum connected to the jackhammer bit; 3) GEV system - hopper on the back of the concrete drum is sealed with a vinyl tarp and connected via ducting to a fan located on the ground, exhaust is connected to a bag to prevent dust generated during the operation from entering the general atmosphere; and 4) LEV and GEV systems combined - during this scenario, both GEV and LEV systems are connected and used during the chipping operation. These four types of controls were used in randomized sets of four. The results presented here involve 17 trials and for some of the trials more than one truck was used. (Also, in the fourth set, there were two no control trials.) In each trial, the two workers alternated work sessions, since they were each to work for about thirty minutes at a time. Each worker wore his own sampler (described below), used during all his sessions in that trial. For the first seven trials, the same control setting was used for the entire day's work, even if that involved more than one truck. For later trials, an effort was made to use only one control setting per truck, though for some trucks containing larger quantities of hardened concrete, more than one control was evaluated per truck. For the first five days of sampling, air samples were collected over the entire work shift; however, the actual time the worker was in the drum was later estimated from the sampling sheet records. The estimated time working in the drum was used to calculate the sample concentrations of total respirable particulate and respirable silica. The sample time when the worker was not chipping in the drum was treated as though there was no exposure to the analyte. For later trials, the sample pumps were turned on only during the actual time the worker was in the truck drum. For the two no-control trials in the fourth set, there was some sampling time during which little chipping was done. For these reasons, it seems sensible to regard our conclusions from these data as applying only to the observed trials, rather than to regard them as applying to a larger population of trials. This affects the data analysis, as described below.

During the site visit, information pertinent to process operation and control effectiveness (e.g. control methods, ventilation rates, work practices, use of personal protective equipment, etc.) was also collected. A thorough description of the process is essential to understanding the role of engineering controls and work practices. The work practices and use of personal protective equipment were also recorded for each worker sampled. Information was obtained from conversations with workers to determine if the sampling day was a typical work day. This information helped place the sampling results in proper perspective. Plant and process layout diagrams were also obtained.

Pertinent data on the employer and the industry were also collected. This information included the number of employees by job title, products produced, processes used, and work schedules. Information gathered about the facility or building(s) included the type of building construction, descriptions of general ventilation present, and age of the facility. This information is helpful for understanding the operations and processes being sampled.

AIR SAMPLING

This section presents the sampling, analytical, and engineering evaluation methods used during the course of this study to measure workplace levels of respirable crystalline silica and to assess the effectiveness of control measures.

The effectiveness of the control measures was evaluated primarily by collecting PBZ air samples for respirable crystalline silica during employee entry into the mixing drum. The purpose of air sampling was to obtain employee PBZ air concentration data to determine the effectiveness of the particular control measure or combination of control measures being used.

Respirable particulate samples were collected at a flow rate of 1.7 liters per minute (ℓpm) using a 10-mm nylon cyclone (a Dorr-Oliver cyclone) and a pre-weighed, 37-mm diameter, 5-µm pore-size polyvinyl chloride filter in accordance with NIOSH Method 7500. Worker exposures were measured by placing a battery operated sampling pump on the workers with the air sampler placed in the workers' breathing-zone. The samples were than analyzed at a laboratory for respirable mass and respirable crystalline silica mass (quartz and cristobalite fraction). From these analytical results, the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for respirable particulate containing crystalline silica, the total respirable particulate concentrations and the respirable crystalline silica concentrations were then calculated for each of the samples collected.

Sample data sheets were filled out by the field survey team to document all of the samples collected. Information contained on the sample sheets included: facility name, facility location, process name, worker identifier (included only to allow the "matching" of samples from the same worker on different days), job title and task performed, pump number, pump flow rate, start times, stop times, and filter number. In addition, any unusual conditions, work practices, and use of personal protective equipment were also noted.

NIOSH researchers calculated the exposures from the analytical results. When the analysis of a sample resulted in a value less than the limit of detection (LOD) of the analytical method, the LOD divided by the square root of 2 (√2) was substituted. (Reference: Hornung, R.W. and L.D. Reed. "Estimation of Average Concentration in the Presence of Non-detectable Values." Applied Occupational and Environmental Hygiene, 5(1), 1990, pp. 46-51.) (LODs are: respirable dust, 0.02 mg/m^3; quartz, 0.01 mg/m^3; cristobalite, 0.02 mg/m^3). No personal samples yielded results less than the LOD. However, almost all field blanks did, for the three fractions of interest- total respirable particulate, respirable quartz, and respirable cristobalite. One quartz blank exceeded the LOD, and the average quartz blank was estimated by averaging this value with the 12 other blank values, for which LOD/√2 had been substituted. All quartz masses were then corrected for the blank value before determining concentration. Blank correction was also used for both respirable and cristobalite fractions. Since these fractions had no blank determinations greater than the LOD, LOD/√2 was the blank correction. Thereby, all fractions are treated consistently. Alternatively, non blank-corrected results were obtained, and the conclusions differ little from those presented below - except that the geometric means for total silica are somewhat higher when no blank correction was made.

VIDEO EXPOSURE MONITORING

Video Exposure Monitoring (VEM) was performed during some of the chipping operations being conducted by workers using jackhammers within the concrete mixing drums. VEM is a technique that employs a video camera and a direct-reading instrument, along with the synchronization of the internal clocks of both the camera and the instrument is required. The direct-reading instrument used is capable of storing the data measurements over one-second intervals. For this particular study, the Haz-Dust II personal dust monitor (manufactured by Environmental Devices Corporation) served as the direct-reading instrument. The dust monitor sampled air from the worker's breathing zone at a rate of 2.0 ℓpm. The resulting concentrations of all respirable dusts, including silica, were downloaded to a notebook PC immediately following the sampling session. As the worker's dust exposure was being collected, a 8mm video camera was recording the worker's movement inside the mixing drum. The camera was mounted on a tripod, with its lens peering into the mixing drum through the access hatch opening. The exposure data are later combined with the videotape. The data appear as a moving bar graph that is superimposed at the edge of the viewing screen. The VEM technique is an excellent tool for illustrating cause and effect relationships in the working environment.

V. RESULTS

The results section is broken into three subsections. Subsection A, table 1, presents the results of air sampling on two days when the workers used no controls. These samples are averaged over the eight-hour work shift for comparison to the OSHA PEL, which is based on an eight-hour work shift. Subsection B, Tables 2 thru 4, present the results of days when the workers used a single control strategy, exclusively, throughout the eight-hour work shift; and Table 5 presents a summary of these results for comparison of the reductions achieved using the three control strategies. Days when more than one control were used are not included in these analyses, but are included in the statistical analyses later in this section. Subsection C, presents a statistical analysis of all sample measurements for the four control scenarios, the individual sample results are presented in Attachment 1. It is important to note that, silica concentrations presented in Attachment 1 represent exposure concentrations for the sample period only, and therefore are not directly comparable to the OSHA eight-hour PEL.

Again, it is important to note that because of the experimental nature of this study only the data presented in Table 1 are considered to be representative of normal workday exposures at this facility, when workers were using the company's jackhammer without LEV or GEV. Other days involved workers using various controls designed by the NIOSH researchers or combinations of those controls, additionally, the sample periods varied by experimental design and were of short duration.

A. EIGHT-HOUR TWA, AIR SAMPLING RESULTS, USING NO CONTROLS

Eight-hour time-weighted average (TWA) concentrations for the two employees conducting the drum cleaning operations with no controls, are presented in Table 1. The respirable silica sample concentrations presented in this table represent the employees exposure only for those days that the employees were operating using the company's jackhammer and normal operating conditions. That is, the employees conducted the cleaning operation using the company's jackhammer without the benefit of local exhaust ventilation (LEV) or general exhaust ventilation (GEV). The eight-hour silica sample results show that the two drum cleaners were exposed to silica concentrations in excess of the NIOSH REL for respirable silica, and the OSHA PEL for respirable dust containing 1% quartz or more. The geometric mean respirable dust concentration was 1.52 mg/m^3, and the geometric mean respirable silica concentration was 0.189 mg/m^3.

TABLE 1
Eight-hour TWA Respirable Silica Concentrations (mg/m^3) for *No control* scenario.

Sample Date	Employee ID	Sample Time (minutes)	Silica Percent	8-Hour TWA Respirable Dust Concentration (mg/m^3)	Silica PEL	8-Hour TWA Respirable Silica Conc. (mg/m^3)
1/14/1999	Emp. #1	90*	12.2	**2.79**	0.70	**0.34**
1/14/1999	Emp. #2	90*	13.3	**1.28**	0.66	**0.17**
1/22/1999	Emp. #2	85	11.5	**1.16**	0.74	**0.13**
1/22/1999	Emp. #1	114	13.1	**1.29**	0.66	**0.17**
	Geometric Mean Concentration			1.52		0.189

Abbreviations: mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
Sample Time: represents time working in concrete drum
* estimated time working in concrete drum

Samples exceeding the OSHA PEL for respirable dust containing 1% quartz or more, are shown in **bold** type and samples exceeding the NIOSH REL of 0.05 mg/m^3 for respirable silica are shown in **bold** type.

B. COMPARISON OF REDUCTIONS ACHIEVED USING CONTROL STRATEGIES

Tables 2 thru 5, present the sample results of days when the workers used a single control strategy, exclusively, throughout the entire work shift. However, to compare the effectiveness of the control strategy the concentrations are averaged over the sample period (time working in drum), not the eight-hour work shift. Table 6 presents a summary of Tables 2 thru 5, for comparison of the actual reductions achieved using the three control strategies.

Air Sample Results, Using No Controls

TWA concentrations for the two employees conducting the drum cleaning operations with no controls, are presented in Table 2. The respirable silica sample concentrations presented in this table represent the employees exposure only for those days that the employees were operating using the company's jackhammer and normal operating conditions. That is, the employees conducted the cleaning operation using the company's jackhammer without the benefit of local exhaust ventilation (LEV) or general exhaust ventilation (GEV). The geometric mean respirable dust concentration was 7.76 mg/m^3, and the geometric mean respirable silica concentration was 0.97 mg/m^3.

TABLE 2
TWA Respirable Silica Concentrations (mg/m^3) for *No control* scenario.

Sample Date	Employee ID	Sample Time (minutes)	Silica Percent	Actual Respirable Dust Concentration (mg/m^3)	Silica PEL	Actual Respirable Silica Conc. (mg/m^3)
1/14/1999	Emp. #1	90*	12.2	**14.88**	0.70	**1.82**
1/14/1999	Emp. #2	90*	13.3	**6.84**	0.66	**0.91**
1/22/1999	Emp. #2	85	11.5	**6.55**	0.74	**0.75**
1/22/1999	Emp. #1	114	13.1	**5.45**	0.66	**0.72**
	Geometric Mean Concentration			7.76		0.97

Abbreviations: mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
Sample Time: represents time working in concrete drum
* estimated time working in concrete drum

Samples exceeding the OSHA PEL for respirable dust containing 1% quartz or more, are shown in **bold** type and samples exceeding the NIOSH REL of 0.05 mg/m^3 for respirable silica are shown in **bold** type.

Air Sample Results Using LEV Control

TWA concentrations for the two employees conducting the drum cleaning operations using the NIOSH LEV control only, are presented in Table 3. The respirable silica sample concentrations presented in this table represent the employees exposure only for those days that the employees were using the NIOSH LEV control, exclusively, for the entire work shift. That is, the employees conducted the cleaning operation using the NIOSH jackhammer equipped with LEV. The geometric mean concentration for respirable dust using LEV was 3.58 mg/m^3, compared to 7.76 mg/m^3 with no controls, a reduction of about 54%. The geometric mean concentration for respirable silica using LEV was 0.30 mg/m^3, compared to 0.97 mg/m^3 with no controls, a reduction of about 69%.

TABLE 3
TWA Respirable Silica Concentrations (mg/m³) using *LEV control.*

Sample Date	Employee ID	Sample Time (minutes)	Silica Percent	Actual Respirable Dust Concentration (mg/m³)	Silica PEL	Actual Respirable Silica Conc. (mg/m³)
1/18/1999	Emp. #2	90*	6.8	**4.29**	1.14	**0.29**
1/18/1999	Emp. #1	120*	7.9	**3.95**	1.01	**0.31**
1/20/1999	Emp. #2	110*	8.1	**3.08**	0.99	**0.25**
1/20/1999	Emp. #1	135*	12.1	**3.16**	0.71	**0.38**
	Geometric Mean Concentration			3.58		0.30

Abbreviations: mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
Sample Time: represents time working in concrete drum
* estimated time working in concrete drum

Samples exceeding the OSHA PEL for respirable dust containing 1% quartz or more, are shown in **bold** type and samples exceeding the NIOSH REL of 0.05 mg/m³ for respirable silica are shown in **bold** type..

Air Sample Results Using GEV Controls

TWA concentrations for the two employees conducting the drum cleaning operations using GEV only, are presented in Table 4. The respirable silica sample concentrations presented in this table represent the employees exposure for those days that the employees were using GEV exclusively, for the entire eight-hour shift. That is, the employees conducted the cleaning operation using the NIOSH GEV system attached to the ready-mix drum hopper. The geometric mean concentration for respirable dust using GEV was 6.42 mg/m³, compared to 7.76 mg/m³ with no controls, a reduction of about 17%. The geometric mean concentration for respirable silica using GEV was 0.73 mg/m³, compared to 0.97 mg/m³ with no controls, a reduction of about 25%.

TABLE 4
Actual TWA Respirable Silica Concentrations (mg/m^3) using *GEV control.*

Sample Date	Employee ID	Sample Time (minutes)	Silica Percent	Actual Respirable Dust Concentration (mg/m^3)	Silica PEL	Actual Respirable Silica Conc. (mg/m^3)
1/21/1999	Emp.#1	69	12.3	**7.55**	0.70	**0.93**
1/21/1999	Emp. #2	113	13.3	**6.23**	0.66	**0.83**
1/29/1999	Emp.#1	116	10.3	**7.79**	0.81	**0.80**
1/29/1999	Emp. #2	92	9.7	**4.64**	0.85	**0.45**
	Geometric Mean Concentration			6.42		0.73

Abbreviations: mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
ND - not detected

Sample Time: represents time working in concrete drum

Samples exceeding the OSHA PEL for respirable dust containing 1% quartz or more, are shown in **bold** type and samples exceeding the NIOSH REL of 0.05 mg/m^3 for respirable silica are shown in **bold** type.

Air Sample Results Using Combined LEV/GEV Controls

TWA concentrations for the two employees conducting the drum cleaning operations using the combined NIOSH GEV and LEV controls, are presented in Table 5. The respirable silica sample concentrations presented in this table represent the employees exposures on the one day that the employees were using the combined NIOSH GEV and LEV controls together for the entire eight-hour shift. That is, the employees conducted the cleaning operation using the NIOSH jackhammer equipped with LEV, and the NIOSH GEV system attached to the ready-mix drum, simultaneously. The geometric mean concentration for respirable dust using GEV and LEV simultaneously, was 2.42 mg/m^3, compared to 7.76 mg/m^3 with no controls, a reduction of about 69%. The geometric mean concentration for respirable silica using GEV and LEV simultaneously, was 0.22 mg/m^3, compared to 0.97 mg/m^3 with no controls, a reduction of about 78%.

TABLE 5
Actual TWA Respirable Silica Concentrations (mg/m³) using *Combined LEV/GEV control* scenario.

Sample Date	Employee ID	Sample Time (minutes)	Silica Percent	Actual Respirable Dust Concentration (mg/m³)	Silica PEL	Actual Respirable Silica Conc. (mg/m³)
1/15/1999	Emp. #2	90*	7.4	**1.74**	1.07	**0.13**
1/15/1999	Emp.#1	90*	10.6	**3.37**	0.79	**0.36**
	Geometric Mean Concentration			2.42		0.22

Abbreviations: mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
Sample Time: represents time working in concrete drum
* estimated time working in concrete drum

Samples exceeding the OSHA PEL for respirable dust containing 1% quartz or more, are shown in **bold** type and samples exceeding the NIOSH REL of 0.05 mg/m³ for respirable silica are shown in **bold** type.

Summary of Reductions Achieved Using the NIOSH Controls

Table 6 shows a summary of the TWA data (Tables 2 thru 5) for days when one control scenario was used exclusively, the entire work shift. These data indicate that the combined effect of using GEV and LEV simultaneously represents a reduction in respirable dust concentrations of about 69%; compared to 54% when using LEV exclusively; and 17% when using GEV exclusively. Respirable silica reductions achieved using GEV and LEV simultaneously were 78%; compared to 69% when using LEV exclusively; and 25% when using GEV exclusively.

TABLE 6
Eight-hour TWA for Respirable Silica Concentrations for the four control scenarios.

Control utilized	Respirable Dust Geometric Mean (mg/m^3)	Reduction	Respirable Silica Geometric Mean (mg/m^3)	Reduction
No control	7.76	Not applicable	0.97	Not applicable
GEV/LEV	2.42	69%	0.22	78%
LEV	3.58	54%	0.30	69%
GEV	6.42	17%	0.73	25%

Results represent sample days when a single control scenario was used during the entire work shift.

C. STATISTICAL ANALYSIS OF ALL AIR SAMPLING RESULTS

Table 7, presents the results of a statistical analysis of all sample data points contained in Attachment 1, regardless of the sample period (time). For each trial, the average of the two workers' concentrations was calculated, one for respirable dust and one for respirable silica. The natural log of each of these averages was used in the statistical models, separate models for respirable dust and for respirable silica. In each model the data were analyzed as a randomized block design, using Proc GLM in SAS. (Reference: **SAS/STAT User's Guide, Version 8, Volume 2.** SAS Institute, Inc., Cary, NC., 1999, "Chapter 30: The GLM Procedure," pp. 1465-1636.) In these models each of the randomized sets of four treatments is treated as having its own mean, so that conclusions apply only to the 17 treatments carried out. It would have been convenient to regard each set as randomly chosen from a larger population of runs. However, there were peculiarities in these data, as mentioned above. Therefore, our analyses treat the set means as fixed, and our conclusions apply only to the 17 trials, not to the larger population of trials from which these were drawn. Also, because there were just two employees, it seems sensible to present the conclusion of this study as applying only to these workers, rather than to the larger population of workers from which they were drawn. The fitted models allow means for the four test conditions, for the four sets, and for the eight combinations of set and local ventilation level (four sets, local ventilation present or not). The inclusion of these (set, local ventilation status) means in the model seems important, since the local ventilation was less effective in the last set than in the first three sets.

The results in Table 7 differ slightly from those in Table 6, due to the way the estimates were calculated. The difference being that only a portion of the data was used to derive the results in Table 6 (i.e., only days when a single control strategy was used during the entire work shift were used for those calculations). Table 7, makes use of all estimated concentrations. The statistical analyses of the sampling results indicate that the use of LEV alone, and the combination of LEV plus GEV, were the most effective controls, reducing airborne silica concentrations by about 57 and 67 percent, respectively. The results, with 95% confidence limits on the reductions, are contained in Table 7, below.

TABLE 7
Geometric Means & Reductions using LEV & GEV
95% Confidence Limits on Reductions

	Total Respirable			**Respirable Silica**		
Controls	Geometric Mean (mg/m^3)	Reduction Achieved	Lower 95% CL*	Geometric Mean (mg/m^3)	Reduction Achieved	Lower 95% CL*
No Control	7.625	—	—	0.932	—	—
GEV/LEV Combined	3.522	54%	29%	0.303	67%	50%
LEV	3.851	49%	27%†	0.405	57%	41%†
GEV	6.519	15%	0%#†	0.724	22%	0%#†

* Individual confidence limits control error rate at 5% for each comparison.
\# A lower confidence limit of 0 indicates no statistically significant reduction.
† For LEV, lower CL indicates minimum reduction with or without GEV; for GEV, lower CL indicates minimum reduction with or without LEV.

The results are quite similar for respirable dust and silica, between 49% and 57% estimated reduction for the LEV, and between 54% and 67% for combined LEV and GEV. (The results for respirable dust and silica should be quite similar, since the correlation between them, based on the 17 pairs on the log scale, is about 0.93.)

The geometric means for respirable silica are shown in the accompanying figures in Attachment 2, by set. Figure 1, shows the set means by presence or absence of LEV. Figure 2, shows the set means by presence or absence of GEV. Clearly, GEV has less benefit than LEV. It should be stated that for respirable silica, the use of GEV (with or without LEV) gives statistically significant reduction in tests at the 93% confidence level. However, for total respirable, where the estimated benefit of using GEV is smaller, even for tests at the 75% confidence level, there is not a statistically significant result. Although there does appear to be a benefit from general ventilation (for respirable silica, an estimated 22% reduction), estimated relative standard deviations, based on the residuals from the fitted model, exceeded 50%. More replication would have been needed to identify a reduction of 22% in statistical tests at the 95% level, when the data have a relative standard deviation of

50%. Similar remarks apply when GEV is used in combination with LEV. For respirable silica, the estimated reduction increases from 57% to 67% when GEV is added to LEV, but this difference is not statistically significant. More replication would have been needed to identify this size difference as statistically significant in tests at the 95% confidence level.

VIDEO EXPOSURE MONITORING

Unlike invisible air contaminants, dust is visible on videotape: the higher the concentration, the more difficult to view the worker. In contrast, with controls operating effectively, VEM associates low dust concentrations with sharper images of the worker. Direct comparisons of VEM data to 8-hour TWA data, and the statistical reduction data, are not possible because the VEM data was limited to 2 hours (a one-half hour session for each control scenario) per individual worker. VEM data are more useful in identifying the causes of elevated peak exposures. As one might expect, the magnitude and frequency of elevated peak exposures to the worker would be greatest in an environment with no controls. The limited VEM data suggest that the use of controls can significantly reduce personal exposures by greater that 20%. Additionally, playback of VEM videotape is useful for revealing instances where the best-designed control can fail to provide full protection. Makeup air enters the mixing-drum through the access hatch. The dust-laden air can only exit through the concrete discharge chute. Elevated peak exposures occur when this air enters the worker's breathing zone. Playback of VEM videotape reveals that elevated peak exposures can, and do, occur when the worker places himself between the source of the contamination (jack hammer) and the control (exhaust opening).

VI. CONCLUSIONS AND RECOMMENDATIONS

The goal of this study is to prevent occupational health problems through the application of control technology and to stimulate private industry to prevent silica exposures to workers involved in the removal of hardened concrete from the interior of mixing drums. The removal of cured concrete from the interior of the truck drum involves entry of personnel into the interior of the concrete mixing drums for the purpose of removing hardened concrete from the interior using a jackhammer.

A review of the eight-hour silica sampling results showed that the two drum cleaners were exposed to silica concentrations in excess of the NIOSH REL and the OSHA PEL. Several actions can be taken to ensure that these workers are adequately protected. First, given the exposures measured, a formal respiratory protection program should be established. The two drum cleaning employees wore a half-face disposable dust mask (3M Model N95 8210), ear plugs plus ear muffs, hard hat, safety boots, and safety glasses when entering the drum interior. The four samples outlined in Table 1, did not exceed the maximum use level (assigned protection factor x REL) for quarter mask respirators, which have an assigned protection factor of 5. For crystalline silica exposures less than or equal to 10 times the NIOSH REL of 0.05 mg/m^3, NIOSH recommends, at a minimum, the use of an approved half-face piece respirator with high efficiency (N100) filters. The issue of filter efficiency is being reviewed, and may be revised by NIOSH at a later date. An effective respiratory protection program includes, but is not limited to, respirator fit-testing, medical monitoring to ensure workers are capable of wearing a respirator, and training on the proper use and care of the respirator.

Although, the four samples outlined in Table 1, of Attachment 1, did not exceed the maximum use level (assigned protection factor x REL) for half mask respirators with HEPA filters, the levels measured did exceed the NIOSH REL when the samples are average over the sample period. Several actions can be taken to ensure that these workers are adequately protected. First, given the exposures measured, a formal respiratory protection program should be established. An effective respiratory protection program includes, but is not limited to, respirator fit-testing, medical monitoring to ensure workers are capable of wearing a respirator, and training on the proper use and care of the respirator. Secondly, because of the dusty conditions produced during the drum cleaning operation adequate eye protection is warranted. Repeated exposure of the eyes to dust increases the risk for injury and disease. Most dust particles entering a person's eyes will be washed out by tears, but some particles can be retained, particularly within the margin of the upper eyelid. Depending on their size, shape, and composition, these particles can become embedded in the surface of the cornea or sclera, where they cause irritation and then reddening of the surface. If not removed, such particles may produce an ulcer and infection. Therefore, a half-facepiece respirator is a poor choice for use in dusty conditions. While wearing eyecup goggles may provide some eye protection, they are not airtight and do not completely prevent dust exposure. Furthermore, goggles may interfere with a respirator's fit. For these reasons, a full-facepiece respirator is a better alternative when a person's eyes are at risk of exposure to airborne dusts.

A statistical review of the control sample data indicates that the use of the LEV apparatus studied here (with or without GEV) reduced personal exposure to both total respirable particulate and respirable silica by between 49% and 57%, and that this reduction is statistically significant at the 95% confidence level. For combined LEV and GEV the estimated reductions were between 54% and 67%, though, at the 95% confidence level, there is no benefit to adding GEV to the LEV. Analogously, the estimated reductions (between 15% and 22%) associated with GEV (with or without LEV) were much smaller, and did not yield statistically significant results at the 95% confidence level, when compared to no control.

To adequately protect the workers during the drum cleaning operation it is recommended the workers wear any air-purifying, full face-piece respirator with a high-efficience particulate filter, preferably a powered air-purifying respirator. This would provide protection up to 50 X the NIOSH REL and provide adequate eye protection.

Further research needs include: investigating the use of alternative methods for removing hardened concrete from the drum interior; investigating the use of other more efficient vacuum systems with HEPA filters; and investigating the use of wet methods to suppress dust generation during removal operations.

Attachment 1
Individual Sample Results
Hilltop Basic Resources, Inc.

Sample Date	Employee ID	Flow Rate	Sample Time (minutes)	Sample Volume (liters)	Silica Percent	Total Resp. Conc. (mg/m3)	Silica PEL	Respirable Silica Conc. (mg/m3)	Control codes
1/14/1999	Emp. #1	1.7	90*	153.0	12.2	**14.88**	0.70	**1.82**	1=NC
1/14/1999	Emp. #2	1.7	90*	153.0	13.3	**6.84**	0.66	**0.91**	1=NC
1/15/1999	Emp. #2	1.7	90*	153.0	7.4	**1.74**	1.07	0.13	4=COMB
1/15/1999	Emp. #1	1.7	90*	153.0	10.6	**3.37**	0.79	0.36	4=COMB
1/18/1999	Emp. #2	1.7	90*	153.0	6.8	**4.29**	1.14	0.29	2=LEV
1/18/1999	Emp. #1	1.7	120*	204.0	7.9	**3.95**	1.01	0.31	2=LEV
1/19/1999	Emp. #2	1.7	60*	102.0	7.1	**9.76**	1.10	0.69	3=GE
1/19/1999	Emp. #1	1.7	60*	102.0	10.7	**17.31**	0.79	**1.85**	3=GE
1/20/1999	Emp. #2	1.7	110*	187.0	8.1	**3.08**	0.99	0.25	2=LEV
1/20/1999	Emp. #1	1.7	135*	229.5	12.1	**3.16**	0.71	0.38	2=LEV
1/21/1999	Emp. #1	1.7	69	117.3	12.3	**7.55**	0.70	**0.93**	3=GE
1/21/1999	Emp. #2	1.7	113	192.1	13.3	**6.23**	0.66	**0.83**	3=GE
1/22/1999	Emp. #2	1.7	85	144.5	11.5	**6.55**	0.74	**0.75**	1=NC
1/22/1999	Emp. #1	1.7	114	193.8	13.1	**5.45**	0.66	**0.72**	1=NC
1/25/1999	Emp. #1	1.7	101	171.7	4.6	1.08	1.51	0.05	4=COMB
1/25/1999	Emp. #2	1.7	33	56.1	5.9	**2.60**	1.27	0.15	4=COMB
1/25/1999	Emp. #2	1.7	86	146.2	13.4	**5.03**	0.65	**0.67**	2=LEV
1/25/1999	Emp. #1	1.7	148	251.6	10.6	**1.30**	0.79	0.14	2=LEV
1/26/1999	Emp. #2	1.7	63	107.1	9.0	**8.65**	0.91	0.78	4=COMB
1/26/1999	Emp. #1	1.7	96	163.2	8.4	**7.88**	0.96	0.67	4=COMB
1/27-28/1999	Emp. #1	1.7	114	193.8	8.4	**12.83**	0.96	**1.08**	1=NC
1/27-28/1999	Emp. #2	1.7	77	130.9	8.6	**18.46**	0.94	**1.59**	1=NC
1/29/1999	Emp. #1	1.7	116	197.2	10.3	**7.79**	0.81	0.80	3=GE
1/29/1999	Emp. #2	1.7	92	156.4	9.7	**4.64**	0.85	0.45	3=GE
2/1-2/1999	Emp. #1	1.7	212	360.4	15.9	**4.87**	0.56	**0.77**	1=NC
2/1-2/1999	Emp. #2	1.7	132	224.4	11.9	**3.32**	0.72	0.39	1=NC
2/2/1999	Emp. #1	1.7	66	112.2	14.0	**6.92**	0.63	**0.97**	4=COMB
2/2/1999	Emp. #2	1.7	33	56.1	ND	1.00	5.00	ND	4=COMB
2/3-4/1999	Emp. #1	1.7	240	408.0	14.0	**6.46**	0.63	**0.90**	2=LEV
2/3-4/1999	Emp. #2	1.7	155	263.5	11.2	**4.35**	0.76	0.49	2=LEV
2/5/1999	Emp. #1	1.7	52	88.4	14.6	**6.18**	0.60	**0.90**	1=NC
2/5/1999	Emp. #1	1.7	102	173.4	13.8	**2.57**	0.63	0.36	3=GE
2/5/1999	Emp. #2	1.7	54	91.8	11.8	**3.66**	0.73	0.43	3=GE

bbreviations: mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
ND - not detected
* estimated time working in concrete drum

Control codes: NC = no controls
LEV = local exhaust ventilation
GE = general exhaust ventilation
COMB = combination LEV and GE

tal respirable dust concentrations in **BOLD** type exceed the OSHA PEL for the sample period.

spirable silica concentrations in **BOLD** type exceed the NIOSH REL.

Attachment 1
Individual Sample Results
Hilltop Basic Resources, Inc.

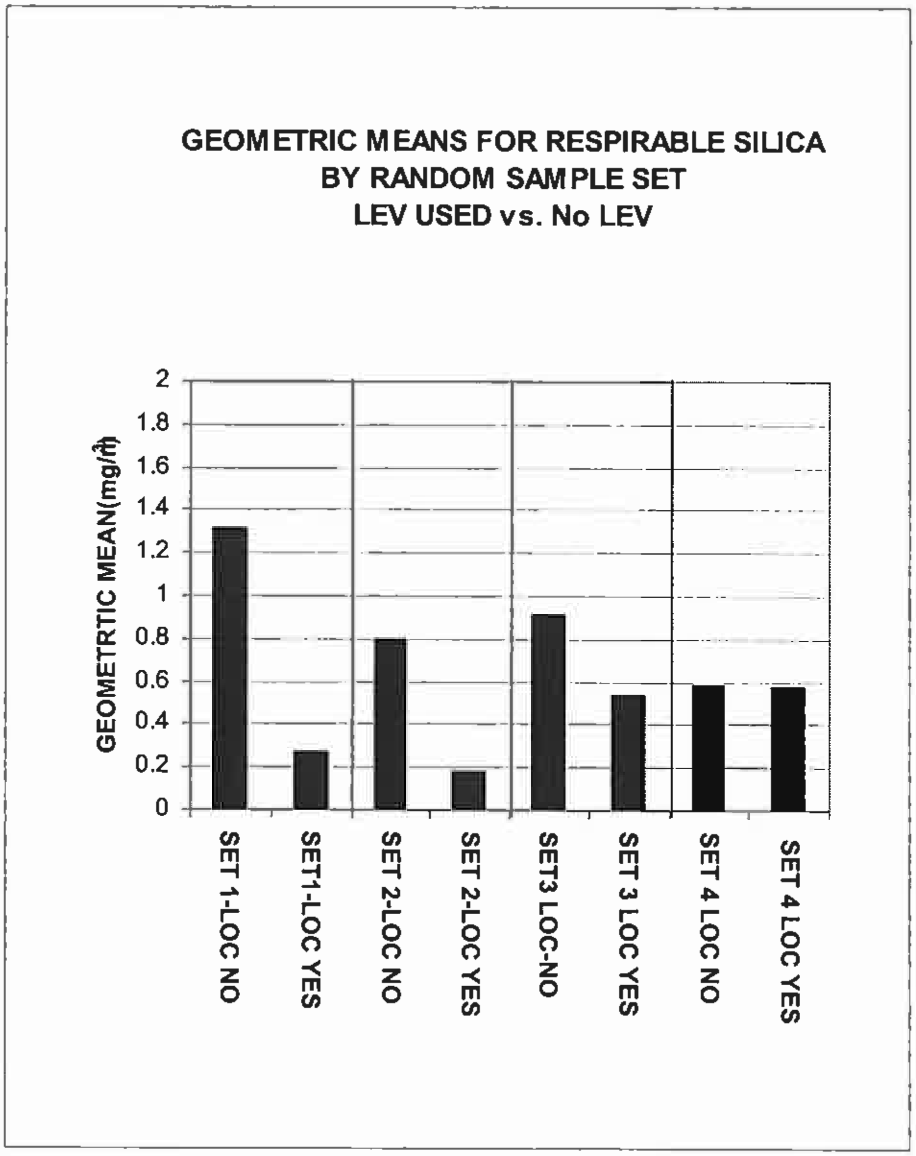
Sample Date	Employee ID	Flow Rate	Sample Time (minutes)	Sample Volume (liters)	Silica Percent	Total Resp. Conc. (mg/m3)	Silica PEL	Respirable Silica Conc. (mg/m3)	Control codes
2/8/1999	Emp. #1	1.7	82	139.4	12.5	**7.93**	0.69	**0.99**	1=NC
2/8/1999	Emp. #2	1.7	103	175.1	9.9	**9.74**	0.84	**0.96**	1=NC
2/10/1999	Emp. #1	1.7	44	74.8	13.3	**12.91**	0.65	**1.72**	1=NC
2/10/1999	Emp. #1	1.7	40	68.0	10.3	**14.06**	0.81	**1.45**	1=NC
2/10/1999	Emp. #1	1.7	51	86.7	8.3	**2.72**	0.97	0.23	1=NC
2/10/1999	Emp. #2	1.7	59	100.3	10.2	**21.30**	0.82	**2.18**	1=NC
2/10/1999	Emp. #1	1.7	38	64.6	14.2	**15.11**	0.62	**2.15**	1=NC
2/10/1999	Emp. #1	1.7	18	30.6	ND	**6.08**	5.00	ND	1=NC
2/11/1999	Emp. #1	1.7	56	95.2	13.8	**2.79**	0.63	0.38	3=GE
2/11/1999	Emp. #2	1.7	52	88.4	10.4	**5.72**	0.81	0.60	3=GE
2/11/1999	Emp. #1/#2	1.7	56	95.2	11.8	**4.58**	0.72	0.54	1=NC
2/12/1999	Emp. #2	1.7	27	45.9	ND	1.44	5.00	ND	1=NC
2/12/1999	Emp. #1	1.7	34	57.8	6.3	**2.35**	1.20	0.15	1=NC
2/12/1999	Emp. #2	1.7	28	47.6	5.5	**3.28**	1.33	0.18	1=NC
2/12/1999	Emp. #1	1.7	28	47.6	ND	1.80	5.00	ND	1=NC

Abbreviations:
mg/m3 - milligrams per cubic meter
PEL - OSHA permissible exposure limit
ND - not detected
* estimated time working in concrete drum

Control codes:
NC = no controls
LEV = local exhaust ventilation
GE = general exhaust ventilation
COMB = combination LEV and GE

Total respirable dust concentrations in **BOLD** type exceed the OSHA PEL for the sample period.
Respirable silica concentrations in **BOLD** type exceed the NIOSH REL.

Attachment 2
Figure 1
LEV EFFECTIVENESS



Attachment 2
Figure 2
GEV EFFECTIVENESS