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Respirable Concrete Dust—Silicosis Hazard in the Construction Industry

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Concrete is an extremely important part of the infrastructure of modern life and must be replaced as it ages. Many of the methods of removing, repairing, or altering existing concrete structures have the potential for producing vast quantities of respirable dust. Since crystalline silica in the form of quartz is a major component of concrete, airborne respirable quartz dust may be produced during construction work involving the disturbance of concrete, thereby producing a silicosis hazard for exposed workers. Silicosis is a debilitating and sometimes fatal lung disease resulting from breathing microscopic particles of crystalline silica. Between 1992 and 1998, the National Institute for Occupational Safety and Health (NIOSH) made visits to construction projects where concrete was being mechanically disturbed in order to obtain data concerning respirable crystalline silica dust exposures. The construction activities studied included: abrasive blasting, concrete pavement sawing and drilling, and asphalt/concrete milling. Air samples of respirable dust were obtained using 10-mm nylon cyclone pre-separators, 37-mm polyvinyl chloride (PVC) filters, and constant-flow pumps calibrated at 1.7 L/min. In addition, high-volume respirable dust samples were obtained on 37-mm PVC filters using $\frac{1}{2}''$ metal cyclones (Sensidyne model 18) and constant-flow pumps calibrated at 9.0 L/min. Air sample analysis included total weight gain by gravimetric analysis according to NIOSH Analytical Method 600 and respirable crystalline silica (quartz and cristobalite) using x-ray diffraction, as per NIOSH Analytical Method 7500. For abrasive blasting of concrete structures, the respirable crystalline silica (quartz) concentration ranged up to 14.0 mg/m^3 for a 96-minute sample resulting in an eight-hour time-weighted average (TWA) of 2.8 mg/m^3. For drilling concrete highway pavement the respirable quartz concentrations ranged up to 4.4 mg/m^3 for a 358-minute sample, resulting in an eight-hour TWA of 3.3 mg/m^3. For concrete wall grinding during new building construction the respirable quartz measurements ranged up to 0.66 mg/m^3 for a 191-minute sample, resulting in an eight-hour TWA of 0.26 mg/m^3. The air sampling results for concrete sawing ranged up to 14.0 mg/m^3 for a 350-minute sample resulting in an eight-hour TWA of 10.0 mg/m^3. During the milling of asphalt from concrete highway pavement, the sampling indicated a respirable quartz concentration ranging up to 0.34 mg/m^3 for a 504-minute sample, resulting in an eight-hour TWA of 0.36 mg/m^3. The results of this work indicate the potential for respirable quartz concentrations involving disturbance of concrete to range up to 280 times the NIOSH Recommended Exposure Limit (REL) of 0.05 mg/m^3 assuming exposure for an eight- to ten-hour workday. Considering the aging of the concrete infrastructure in the United States, these results pose a challenge to all who have an interest in preventing silica exposures and the associated disease silicosis.

Keywords Construction, Silica Dust, Crystalline Silica Dust, Concrete Dust, Construction Dust, Concrete Sawing, Concrete Drilling, Concrete Grinding, Concrete Abrasive Blasting, Concrete Milling

Between 1992 and 1998, the National Institute for Occupational Safety and Health (NIOSH) made visits to construction projects in order to obtain information about respirable crystalline silica dust exposures. Crystalline silica is well known as the cause of the debilitating and sometimes fatal lung disease silicosis. Twelve of the visited construction sites involved dust exposures resulting from disturbance of concrete. The sampled activities included: abrasive blasting, concrete pavement sawing and drilling, and asphalt/concrete milling. The locations were in Ohio, Pennsylvania, West Virginia, and Washington, DC. The sites were chosen on an opportunistic basis, meaning that when a construction site was known to involve an activity of interest, a visit was made. Since NIOSH needed to work with each company to determine the best time to visit, the data presented here was gathered from work sites that had advance notice.

BACKGROUND

The history of concrete goes back at least 2,000 years. The Romans in the 3rd century B.C. made a cement with lime, which led to the making of clay bricks. Later, a naturally occurring silica- and alumina-bearing material that made a stronger cement was used. When the Roman Empire fell, the use of cement was forgotten until the Renaissance. Then in 1824, a brick mason (Joseph Aspdin) in Leeds, England, formulated a new cement that had the color of the rock on the island of Portland in the English Channel. Aspdin called the new cement, which was mostly calcium silicates, portland cement.[(1)] Portland cement is made mainly of limestone and clay that is calcined at approximately 2,700°F, and then combined with a small amount of gypsum.[(1)] The formulation or additives used may vary depending on the availability of raw materials and the type of portland cement required for a specific application.

Concrete is made by mixing cement with aggregates (crushed and sized stone and silica sand) and water. Aggregates make up 60 to 75 percent of the volume of concrete. Sand makes up one-third to one-half of the volume of the aggregate. Strong concrete contains aggregates of various sizes. These may include sand ranging in size from very fine to 1/4 inch and stone ranging from 3/8 inch up to the largest aggregate used for the particular application. Crushed stone, sand, and air-cooled blast furnace slag are the most common aggregates and produce a normal-weight concrete. If a lightweight concrete is desired, expanded shale, clay, slate, and slag are used, and if concrete with insulating properties is desired, pumice, scoria, perlite, vermiculite, and diatomite are used.[(1)]

Concrete may be improved for a particular use by adding a variety of admixtures. Water-reducing admixtures (hydroxylated carboxylic acid) are added so that less water can be used, thereby making stronger, more workable concrete. Many chemicals may be added as retarders to slow setting time and to allow less water to be used. Accelerators such as calcium chloride are used to reduce the setting time of concrete. Air-entraining agents are added to provide microscopic air bubbles, which improves the workability and durability of concrete especially for applications where frost and salt for snow/ice removal is a concern. These agents include wood resin, sulfonated hydrocarbons, and fatty resinous acids. Air-entraining agents also allow less water to be used.[(1)]

Modern tools such as pneumatic hammers and drills and powerful saws, grinders, chippers, and mills are often used to disturb concrete structures such as highways, bridges, and buildings. These tools, if not operated with adequate dust controls, will produce respirable crystalline silica dust from use on concrete, masonry, and/or mortar. In addition, concrete is abrasive-blasted either with silica sand or other abrasives to provide a textured surface, as a result of bridge maintenance, during pavement joint/crack cleaning, and during refurbishment of the outside of older buildings. Too often, the dust produced from these processes is not adequately controlled. Some tools do not come equipped with dust control or it is an option that is not always purchased. Some dust controls remove large particles that are visible, but allow the smaller sized particles to escape into the air, thereby giving the false appearance of adequate dust control. Some tools may not have commercially available dust controls. In some cases the work practice or procedure could be changed to eliminate the need for the dust producing tool or task.

In 1974 NIOSH published its criteria for a recommended standard for occupational exposure to crystalline silica.[(2)] In this document NIOSH established its recommended exposure limit (REL) for respirable crystalline silica of 0.05 mg/m^3 as a time-weighted average (TWA) for up to 10 hours per day during a 40-hour workweek.[(2)] In 1999, NIOSH reported that the construction industry is mentioned on death certificates when silicosis is present more often than any other industry (for the period 1987–1996).[(3)] In a review of death certificate data for primary cause of death for 100,799 white male construction workers in 28 states who died before age 65, between 1979 and 1990, NIOSH found the proportionate mortality ratio (PMR) for silicosis to be 210 ($p \leq 0.05$), or over twice that of white men employed in all industries, and second only to the PMR for asbestosis.[(4)]

A recent NIOSH examination of Occupational Safety and Health Administration (OSHA) compliance data recorded in the agency's Integrated Management Information System (IMIS) indicates that the Standard Industrial Classification (SIC) code 174 (Masonry, Stonework, Tile Setting, and Plastering) may have more workers exposed to crystalline silica dust at levels above 10 times the NIOSH REL of 0.05 mg/m^3 than any other 3-digit SIC (excluding mining and agriculture).[(5)] This study estimates that 13,800 workers (1.8%) employed in SIC 174 in 1993 were exposed to levels in excess of 10 times the NIOSH REL.[(5)] Indeed, when OSHA compliance officers obtained compliance air samples during the years 1980 through 1995 for inspections classified in the more specific SIC 1741—Masonry, Stone Setting, and Other Stone Work, 39 percent of the silica samples were over the OSHA permissible exposure limit (PEL) in force at the time of the inspection.[(6)] Additionally, 20 percent of the silica samples for SIC 1771—Concrete Work exceeded the PEL during OSHA inspections.[(6)] From a 1981–1983 national hazard survey, NIOSH estimated that 132,000 masonry workers (SIC 174) are potentially exposed at 6,700 workplaces, and 18,000 concrete workers (SIC 177) are potentially exposed at 1,500 workplaces.[(5)] In 1996, NIOSH published an alert warning of the silicosis hazard in the construction industry.[(7)]

Concrete is abrasive-blasted for several reasons. Sometimes architects will specify that a building or other concrete structure be abrasive blasted with sand or other materials to etch the surface of the concrete, exposing some of the aggregate for esthetic reasons. Sometimes painters or construction laborers employ abrasive blasting to remove paint from the steel structure of bridges where concrete is adjacent to the steel and is inadvertently abraded in the process. Since concrete has silica sand in it, anytime it is abraded a potential hazard exists, regardless of the abrasive used. If pavement cracks or expansion

FIGURE 1
Altered type CE continuous flow abrasive blasting respirator.

joints are blasted in preparation for sealing, care must be taken to protect the workers engaged in the activity and those working nearby. Abrasive blasting is also used at times to remove traffic lane paint from the surface of pavement. All of these activities have the potential to pose a serious respiratory hazard.

In a study of death certificates from union workers in 19 states (1984–1986), NIOSH reported a silicosis proportionate mortality ratio (PMR) for construction and maintenance painters representing greater than a fourfold increased mortality risk (PMR = 449, p = 0.05).[8] A survey of abrasive blasting practices in 1974 indicated that the general maintenance and care of respiratory protection devices used for abrasive blasting was poor to nonexistent: "Helmets were observed in use with missing face piece seals and protective collars."[9] Figure 1 is a picture of a Type CE continuous flow abrasive blasting respirator in use at the time of a NIOSH Health Hazard Evaluation in 1995.[10] The ricochet guard is open to show that the front glass has been removed. Other respiratory protection deficiencies were found in this study.[10] NIOSH issued its criteria for abrasive blast cleaning operations in 1975.[11]

Steel-reinforced concrete makes up a large portion of the infrastructure in modern civilization. Most of the concern with concrete comes from renovations, repairs, and demolitions of concrete structures. Considering how universally used concrete is and the amount of concrete that is in need of replacement, industrial hygienists should be alert to identify potential silica exposures and silicosis hazards involving the disturbance of concrete.

METHODS

Air samples were taken using 10-mm nylon cyclone preseparators, 37-mm PVC filters, and constant-flow pumps calibrated at 1.7 L/min. High-volume air samples were obtained on 37-mm PVC filters using a $\frac{1}{2}''$ metal cyclone (Sensidyne model 18) and constant-flow pumps calibrated at 9.0 L/min.

The air sample analysis included total weight gain by gravimetric analysis according to NIOSH Analytical Method 600.[12] The limit of detection (LOD) for this procedure is 0.02 mg. The air samples were then analyzed for respirable crystalline silica (quartz and cristobalite) using x-ray diffraction, as per NIOSH Analytical Method 7500.[12] The LOD for quartz on the filters is 0.01 mg and the limit of quantification (LOQ) is 0.03 mg. The LOD for cristobalite on the filters is 0.015 mg and the LOQ is 0.03 mg.

The concentration of respirable dust and respirable quartz were then computed using the formula:

$$\text{Conc.}(\text{mg/m}^3) = \frac{\text{mass collected (mg)}}{\{[\text{flow rate(L/min)}/1000\ \text{L/m}^3] \bullet \text{time sampled (min)}\}} \quad [1]$$

The percent quartz content of a sample may be computed by dividing the quartz mass by the gravimetric mass.

RESULTS

The form of crystalline silica found in the air samples for this study was quartz. None of the air samples involved in this work resulted in the detection of cristobalite. The respirable quartz data is found in Tables I through VI. The quartz concentration measured during the particular work activity (sample period) is presented along with the resulting eight-hour TWA. To calculate the eight-hour TWA it was assumed that no exposure occurred during any nonsampled portion of the shift.

Abrasive Blasting of Concrete

Table I summarizes the concrete abrasive blasting samples for this study. Samples 1–3 were obtained during sandblasting of a concrete wall outdoors. Samples 4–7 and 15–22 were obtained during sandblasting of prestressed concrete building structures inside a ventilated blasting shed. Samples 8–14 were obtained during abrasive blasting of the steel structure under a bridge. Coal slag was used as the abrasive in an unventilated curtained enclosure to abrasive blast the steel structure and presumably the surrounding concrete. Samples 8–14 in Table I indicate a potential for quartz concentrations to exceed the assigned protection factor (APF = 25)[7] for the continuous flow type CE respirator being used.

Concrete Drilling

The dust samples in Table II represent concrete drilling work during interstate highway repair. To repair cracked concrete pavement, large blocks of the pavement are sawed so that the damaged portion can be removed. For small jobs, a jackhammer may be used to break up the heavy block of sawed concrete; for larger jobs a clamshell-type device may be used with a backhoe to lift the block out. Another method is to drill holes through the block and use a crane with a friction type attachment in the

TABLE I
Abrasive blasting of concrete structures

	Agent used	Flow rate L/min	Sample time min	Resp. dust mg/m^3	Resp. quartz mg/m^3	8-hr TWA quartz mg/m^3	Comments
1	Silica	1.7^P	61	8.3	1.8	0.23	Outside type CE respirator
2	Silica	1.7^P	57	1.6	0.52	0.06	Outside type CE respirator
3	Silica	9.0^{A,M}	65	0.96	0.26	0.04	Outside type CE respirator
4	Silica	1.7^P	94	0.06	ND	ND	Inside type CE respirator
5	Silica	1.7^P	94	17.0	11.0	2.2	Outside type CE respirator
6	Silica	1.7^A	194	2.5	1.9	0.77	Area inside vent. shed
7	Silica	9.0^{A,M}	110	0.12	0.05	0.01	Outside of vent. shed
8	Coal slag	2.0^{P,NC}	90	11.0	0.5	0.09	Inside type CE respirator
9	Coal slag	2.0^{P,NC}	90	9.8	0.44	0.08	Outside type CE respirator
10	Coal slag	1.7^P	72	32.0	1.5	0.22	Blaster's helper
11	Coal slag	1.7^A	96	40.0	1.7	0.35	Area 1 inside enclosure
12	Coal slag	9.0^{A,M}	96	200.0	14.0	2.8	Area 1 inside enclosure
13	Coal slag	1.7^A	93	66.0	3.0	0.57	Area 2 inside enclosure
14	Coal slag	1.7^A	93	19.0	0.82	0.16	Area 2 inside enclosure
15	Silica	1.7^A	40	0.59	ND	ND	Area 1 inside vent. shed
16	Silica	1.7^A	40	0.88	ND	ND	Area 1 inside vent. shed
17	Silica	1.7^A	40	10.0	2.5	0.21	Area 2 inside vent. shed
18	Silica	1.7^A	40	1.9	(0.4)	(0.03)	Area 2 inside vent. shed
19	Silica	1.7^A	39	2.3	(0.15)	(0.01)	Area 3 inside vent. shed
20	Silica	1.7^A	39	9.5	2.3	0.18	Area 4 inside vent. shed
21	Silica	1.7^A	39	6.3	0.75	0.06	Area 4 inside vent. shed
22	Silica	1.7^A	39	12.0	3.6	0.29	Area 5 inside vent. shed

^{P}Denotes personal sample.
^{NC}Denotes no cyclone.
^{A}Denotes area sample.
NDDenotes not detected.
^{M}Denotes metal cyclone.
( )Denotes result is between the LOD and LOQ.

holes to lift the concrete block. After the broken pavement is removed, steel reinforcement is installed before new concrete is placed into the hole. To key the new concrete into the surrounding pavement, horizontal holes are drilled into the surrounding concrete so that steel rods can be anchored in these holes with epoxy. After an additional steel reinforcement bar is tied off, the new concrete is placed. A typical rig to drill the holes is a set of three pneumatic drills in a carriage that is used as an attachment to a backhoe.

Table II presents data from two interstate highway construction sites (samples 1–8 and 9–22) where this concrete drilling procedure was being performed. In Figure 2, a laborer is seen stationed at the pneumatic drills. A heavy equipment operator is stationed in the cab of the backhoe (not seen, but off to the right in Figure 2). Typically, this drilling is done dry without any dust control. Clouds of dust can be seen drifting from these types of operations. The laborer at the controls of the drill works in higher dust concentrations than the operator of the backhoe; however, the laborer can, at times, move out of the direction that the dust is moving, while the operator has to sit in the cab. Often these cabs are not enclosed or, if enclosed, do not provide adequate protection from respirable dust.

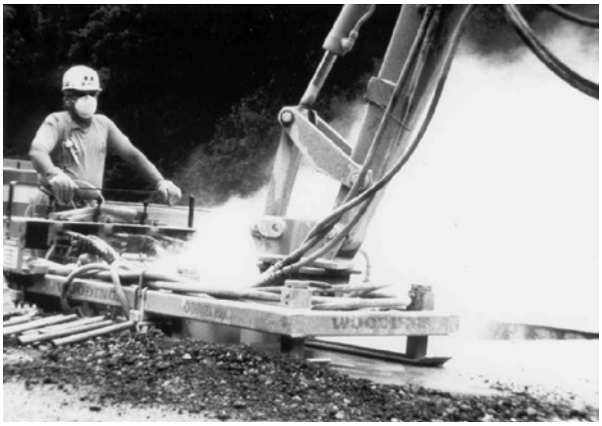

FIGURE 2
Drilling dowel holes into concrete pavement.

TABLE II
Drilling concrete pavement

	Sample location	Flow rate L/min	Sample time min	Resp. dust mg/m^3	Resp. quartz mg/m^3	8-hr TWA quartz mg/m^3
1	Operator	1.7[P]	206	0.49	ND	ND
2	Laborer	1.7[P]	212	4.9	0.81	0.36
3	Operator	1.7[P]	201	0.76	(0.03)	(0.01)
4	Laborer	1.7[P]	203	2.8	0.41	0.17
5	Operator	1.7[P]	209	0.9	0.08	0.03
6	Laborer	1.7[P]	207	3.7	0.42	0.18
7	Operator	1.7[P]	185	1.6	(0.06)	(0.02)
8	Laborer	1.7[P]	185	2.7	0.32	0.12
9	Area	9.0[A,M]	509	0.44	0.03	0.03
10	Operator	1.7[P]	512	1.2	(0.05)	(0.05)
11	Laborer	1.7[P]	519	2.2	0.16	0.17
12	Area	9.0[A,M]	522	19.0	2.2	2.4
13	Operator	1.7[P]	518	2.0	0.10	0.11
14	Laborer	1.7[P]	514	12.0	1.2	1.3
15	Area	9.0[A]	375	5.4	0.64	0.50
16	Operator	1.7[P]	300	1.1	(0.04)	(0.03)
17	Laborer	1.7[P]	299	2.0	0.20	0.12
18	Area	9.0[A,M]	358	34.0	4.4	3.3
19	Operator	1.7[P]	348	1.9	0.12	0.09
20	Laborer	1.7[P]	348	4.4	0.46	0.33
21	Area[V]	9.0[A]	377	0.34	0.06	0.05
22	Operator[V]	1.7[P]	382	0.14	ND	ND

[P]Denotes personal sample.
[NC]Denotes no cyclone.
( )Denotes result is between the LOD and LOQ.
[A]Denotes area sample.
[ND]Denotes not detected.
[M]Denotes metal cyclone.
[V]Denotes vertical drill used.

Figure 3 shows two pneumatic drills mounted on a piece of mobile equipment so that vertical holes can be drilled into blocks of concrete pavement. The holes were used to attach a gripping device so that a small crane could lift the concrete block out of the pavement.

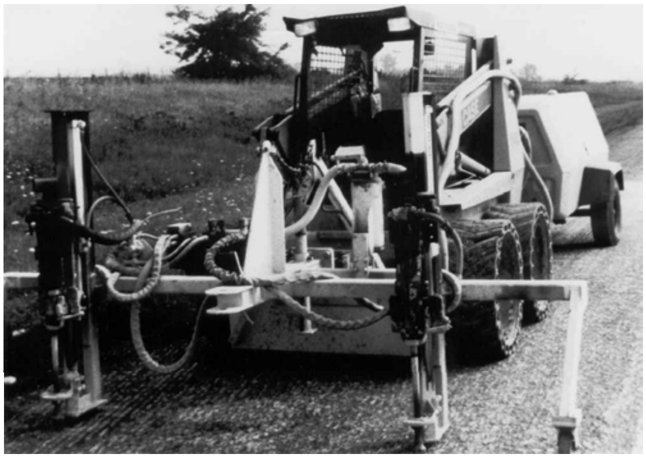

FIGURE 3
Two pneumatic drills mounted to mobile equipment being used to drill concrete pavement.

Concrete Grinding

Tables III and IV present data from a construction site where the concrete walls of a large building were being smoothed using an electric angle grinder equipped with a 4″ diamond-impregnated steel disc. The average quartz content of the airborne respirable dust collected was 6.3 ± 1.6%.

Samples 1–6 in Table III were obtained during concrete grinding without dust control. The personal breathing zone samples indicated a respirable quartz dust concentration of 0.66 mg/m^3 for the 191-minute sample duration. Due to worker breaks and interruptions the estimated actual grinding time was 147 minutes. This concentration represents a potential exposure of over

TABLE III
Concrete grinding wet[D] vs. no control

	Dust control	Flow rate L/min	Sample time min	Resp. dust mg/m^3	Resp. quartz mg/m^3	8-hr TWA quartz mg/m^3	Comments
1	None	1.7[A]	195	3.0	0.16	0.07	Side-by-side area sample
2	None	1.7[A]	195	3.1	0.16	0.07	Side-by-side area sample
3	None	1.7[A]	195	3.1	0.27	0.11	Side-by-side area sample
4	None	1.7[A]	195	3.2	0.14	0.06	Side-by-side area sample
5	None	9.0[A,M]	195	2.6	0.13	0.05	High-volume area sample
6	None	1.7[P]	191	10.7	0.66	0.26	Grinder operator
7	Wet	1.7[A]	340	ND	ND	ND	Side-by-side area sample
8	Wet	1.7[A]	340	0.05	ND	ND	Side-by-side area sample
9	Wet	1.7[A]	340	0.03	ND	ND	Side-by-side area sample
10	Wet	1.7[A]	340	ND	ND	ND	Side-by-side area sample
11	Wet	9.0[A,M]	114	0.16	ND	ND	High-volume area sample
12	Wet	9.0[A,M]	227	0.26	0.02	0.01	High-volume area sample
13	Wet	1.7[P]	342	0.36	(0.02)	(0.01)	Grinder operator
14	Wet	1.7[P]	225	0.16	ND	ND	Helper

[P]Denotes personal sample.
[NC]Denotes no cyclone.
( )Denotes result is between the LOD and LOQ.
[A]Denotes area sample.
[ND]Denotes not detected.
[M]Denotes metal cyclone.
[D]See description of process in text.

13 times the NIOSH REL of 0.05 mg/m^3 for respirable quartz if this procedure were employed for a full shift. If the worker had no other crystalline silica exposure for the remainder of the shift, the exposure would still have been over five times the NIOSH REL.

Samples 7–14 in Table III were obtained during wet grinding. Separate personal breathing zone samples were obtained for the grinder and for the helper. The helper used a new, clean, pesticide-type spray can filled with tap water to wet down the surface of the concrete wall just ahead of where the worker using the grinder was working (see Figure 4). For the grinder, the 342-minute personal breathing zone sample indicated a respirable dust concentration of 0.36 mg/m^3 and a respirable quartz concentration of 0.02 mg/m^3, which was between the limit of detection and limit of quantification for the sample. For the helper, the personal breathing zone sample indicated a respirable dust concentration of 0.16 mg/m^3 for the 225-minute sample duration. Respirable quartz dust was not detected. To be detected and quantified, at least 0.01 mg and 0.03 mg of quartz, respectively, must have been on the filter. The two high-volume area samples (9.0 L/min.) indicated respirable dust concentrations of 0.16 and 0.26 mg/m^3 and respirable quartz concentrations of not detectable and 0.02 mg/m^3, respectively. The data indicate that the respirable quartz concentrations were low but measurable during full-shift sampling. Sample time for the grinder operator personal sample was 342 minutes; however, due to worker breaks and tool problems the estimated actual grinding time was 270 minutes. If grinding occurred during a greater portion of the sampling time, quartz may have been measured in these samples.

Three different local exhaust dust control systems were used (Micro mini-vac, Maxi-vac, and WAP) (see Figure 5). Micro mini-vac and Maxi-vac are two vacuum-type dust collection systems that were made by the same manufacturer. Table IV summarizes the exhaust control system sampling data.

Samples 1–6 in Table IV were obtained while using a dust collection system sold by SawTec named the Micro mini-vac. The system weighs approximately 46 pounds, is 14″W × 52″L × 16-1/2″H and produces 760 CFM air flow at 8.5″ maximum static pressure according to SawTec. The vacuum has one 4″ inlet for a flexible tube. The system uses a bag to collect the suctioned dust. Information with the equipment states that the bag "filters concrete dust to 0.5 micron" (see Figure 6). A metal shroud was attached to the grinder, and a flexible tube connected the vacuum to the shroud. Neither respirable quartz nor respirable dust were detected by the 127-minute personal breathing zone sample. Due to tool and/or system problems the estimated grinding time was 77 minutes. The high-volume area sample (9.0 L/min.) indicated a respirable dust sample concentration of 0.66 mg/m^3 and a respirable quartz sample concentration of

TABLE IV
Concrete grinding, local exhaust ventilation

	Dust control	Flow rate L/min	Sample time min	Resp. dust mg/m^3	Resp. quartz mg/m^3	8-hr TWA quartz mg/m^3	Comments
1	Micro mini	1.7^A	127	0.51	ND	ND	Side-by-side area sample
2	Micro mini	1.7^A	127	0.56	ND	ND	Side-by-side area sample
3	Micro mini	1.7^A	127	0.51	ND	ND	Side-by-side area sample
4	Micro mini	1.7^A	127	0.56	ND	ND	Side-by-side area sample
5	Micro mini	$9.0^{A,M}$	127	0.66	0.04	0.01	High-volume area sample
6	Micro mini	1.7^P	127	ND	ND	ND	Grinder operator
7	Maxi-vac	1.7^A	150	0.47	ND	ND	Side-by-side area sample
8	Maxi-vac	1.7^A	150	0.59	ND	ND	Side-by-side area sample
9	Maxi-vac	1.7^A	150	0.51	ND	ND	Side-by-side area sample
10	Maxi-vac	1.7^A	150	0.55	ND	ND	Side-by-side area sample
11	Maxi-vac	$9.0^{A,M}$	150	0.61	0.03	0.01	High-volume area sample
12	Maxi-vac	1.7^P	150	1.4	0.13	0.04	Grinder operator
13	WAP	1.7^A	120	ND	ND	ND	Side-by-side area sample
14	WAP	1.7^A	120	ND	ND	ND	Side-by-side area sample
15	WAP	1.7^A	120	ND	ND	ND	Side-by-side area sample
16	WAP	1.7^A	120	ND	ND	ND	Side-by-side area sample
17	WAP	$9.0^{A,M}$	120	0.26	(0.02)	(0.01)	High-volume area sample
18	WAP	1.7^P	117	0.30	ND	ND	Grinder operator

^{P}Denotes personal.
^{NC}Denotes no cyclone.
^{A}Denotes area sample.
NDDenotes not detected.
^{M}Denotes metal cyclone.
( )Denotes result is between the LOD and LOQ.

0.04 mg/m^3. The four side-by-side area samples (1.7 L/min.) did not detect respirable quartz, but averaged 0.54 mg/m^3 of respirable dust. The data indicate that short-term sampling may not collect enough dust to permit a quartz measurement. Occasional dust leaks at connections of the air handling system were observed.

Samples 7–12 in Table IV were obtained while using a dust collection system sold by SawTec named the Maxi-vac. According to information available, the system weighs 140 pounds, is 21″W × 36″L × 78″H and produces 900 CFM air flow at 8.5″ maximum static pressure. The vacuum can be arranged for up to two 4″ inlets or one 6″ inlet. The Maxi-vac uses the same bag material as the Micro mini-vac. The Maxi-vac was connected to a shroud on the grinder in a similar fashion as with the Micro mini-vac. The shroud used for this system had a cut-out to allow the disc to reach into corners. The personal breathing zone sample indicated a respirable dust concentration of 1.4 mg/m^3 and a respirable quartz dust concentration of 0.13 mg/m^3 for the 150-minute sample. Due to worker breaks and interruptions the estimated actual grinding time was 96 minutes. This quartz concentration, if maintained for an 8- to 10-hour shift, would be over 2-1/2 times the NIOSH REL. Even if no exposure is assumed for the remainder of the shift, the 8-hour TWA would be 0.04 mg/m^3. The high-volume area sample (9.0 L/min.) indicated a respirable dust concentration of 0.61 mg/m^3 and a respirable quartz concentration of 0.03 mg/m^3 during the 150-minute sample. The four side-by-side area samples did not detect respirable quartz, but found an average of 0.53 mg/m^3 of respirable dust. Occasional dust leaks at connections of the air handling system were observed.

Samples 13–18 in Table IV were obtained while using a WAP dust collection system, which is a type of canister vacuum. The WAP vacuum has a 10-gallon capacity and uses 1600 watts with 13 amps or 1000 watts with 8.3 amps. The system uses disposable paper filter bags. A flexible tube was used to connect it to a shroud fitted to the grinder. The 117-minute personal breathing zone sample resulted in a respirable dust concentration of 0.30 mg/m^3. Respirable quartz was not detected. Due to worker breaks and interruptions the estimated actual grinding time was 100 minutes. The high-volume area sample (9.0 L/min.) indicated a respirable dust concentration of 0.26 mg/m^3 and a respirable quartz concentration between the limits of detection and quantification of 0.02 mg/m^3. None of the four side-by-side area samples detected respirable dust.

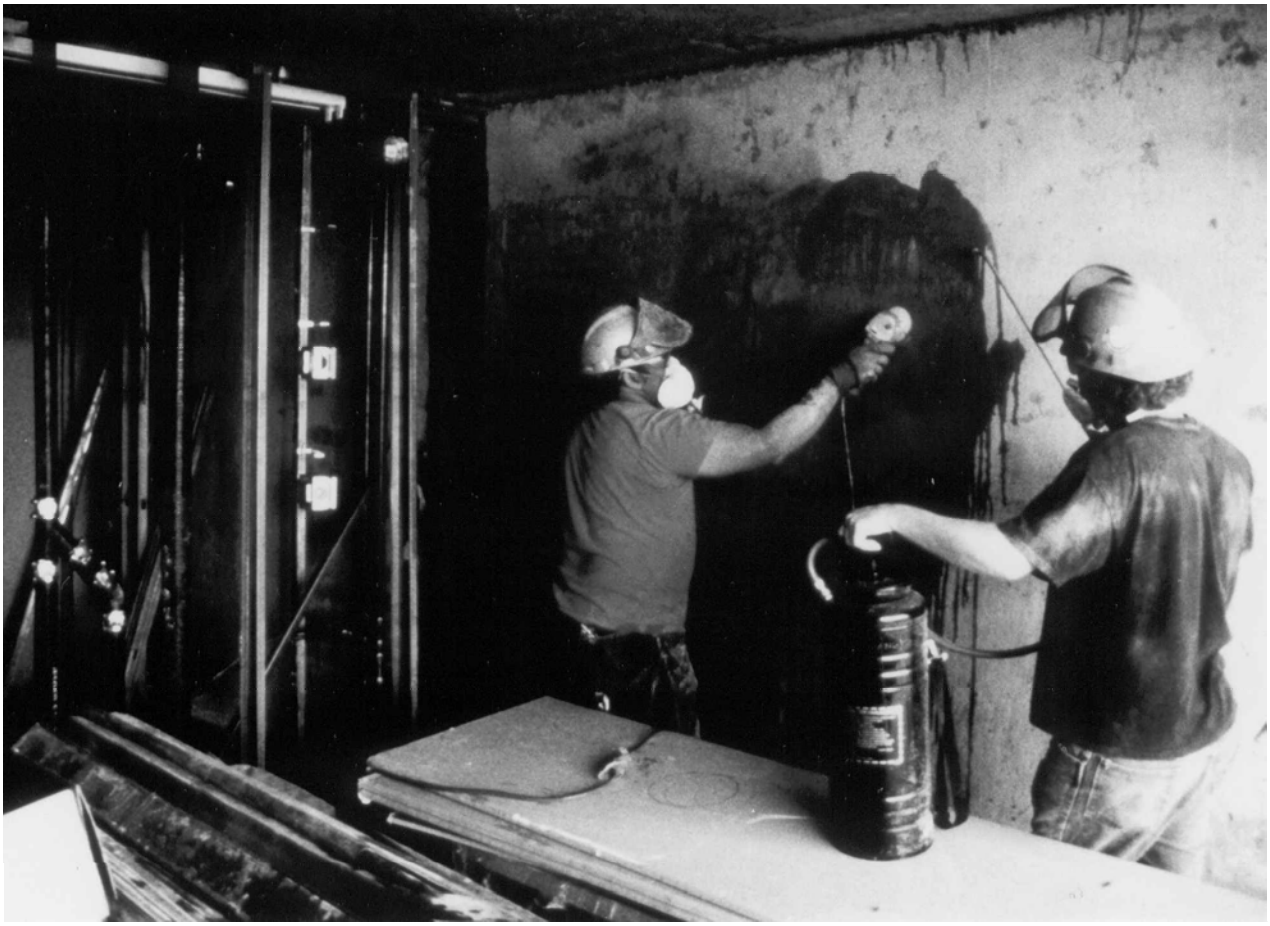

FIGURE 4
Wetting concrete wall during grinding without local exhaust ventilation.

Concrete Sawing

Table V summarizes the concrete sawing data. Samples 1–4 were obtained at an office building remodeling project. A worker used a gasoline-powered handheld masonry saw (see Figure 7) to saw indentations in the concrete floor on each of the 16 floors of the building so that restroom floor drains could be installed. The concrete cutting was done by a plumber. The saw was used without water being applied to the blade or using a dust collector. The only attempt to control the dust was with the use of a floor stand fan directed toward an open window. The investigators found a respirable concentration of quartz for the concrete cutter operator of 14.0 mg/m^3 during a 350-minute sample. The area samples for this operation were found to be 4.1, 3.4, and 3.2 mg/m^3 respirable quartz. Three bulk samples of the concrete dust were found to be 38, 47, and 43 percent silica.

Samples 5–12 were taken during highway construction. This site consisted of a four-lane highway being constructed, during which expansion joints were being sawed in the fresh concrete within six hours of being placed. Three workers were involved in the operation. Two of the workers operated commercial-type walk-behind concrete saws and the third operated a water truck, which provided water to the saws. Hoses transported water from the water truck to the saws so that the diamond-tipped saw blades could be cooled while in use. Neither the saw operators nor the water truck driver used respiratory protection. The water truck driver spent almost all of his time in the cab of the water truck while the saws were in use.

Samples 13–15 were obtained during reconstruction of an interstate highway bridge where blocks of the old concrete were sawed completely through so the old pavement could be removed. This operation consisted of three workers operating concrete saws to saw through the decking of an existing bridge. Each of the saws was equipped with a water supply that provided water to the diamond-impregnated saw blades. Water was obtained from tanks mounted on the back of trucks, and was transported by gasoline pumps to the saws. General area air samples were collected to determine the potential exposure concentrations of respirable silica dust. The duration of the air sampling was approximately three hours, due to inclement weather.

Samples 16–24 were obtained during repair of an interstate highway. Blocks of the old concrete pavement that needed to be replaced were sawed through and lifted out so that new concrete

TABLE V
Concrete sawing

	Saw type	Flow rate L/min	Sample time min	Resp. dust mg/m^3	Resp. quartz mg/m^3	8-hr TWA quartz mg/m^3	Comments
1	Hand-held	1.7[P]	350	29.0	14.0	10.0	Dry sawing concrete floor
2	Hand-held	9.0[A,M]	350	9.1	4.1	3.0	Dry sawing concrete floor
3	Hand-held	1.7[A]	350	7.7	3.4	2.4	Dry sawing concrete floor
4	Hand-held	1.7[A]	350	8.1	3.2	2.3	Dry sawing concrete floor
5	Walk behind	1.7[P]	240	0.02	ND	ND	Wet sawing fresh pavement
6	Walk behind	1.7[P]	242	0.05	ND	ND	Wet sawing fresh pavement
7	Walk behind	1.7[P]	238	0.07	ND	ND	Wet sawing fresh pavement
8	Walk behind	1.7[A]	160	ND	ND	ND	Wet sawing fresh pavement
9	Walk behind	1.7[A]	160	ND	ND	ND	Wet sawing fresh pavement
10	Walk behind	1.7[P]	545	0.05	ND	ND	Wet sawing fresh pavement
11	Walk behind	1.7[P]	545	0.05	ND	ND	Wet sawing fresh pavement
12	Walk behind	1.7[P]	535	0.03	ND	ND	Wet sawing fresh pavement
13	Walk behind	1.7[A]	176	0.33	ND	ND	Wet sawing bridge deck
14	Walk behind	1.7[A]	174	0.71	ND	ND	Wet sawing bridge deck
15	Walk behind	9.0[A,M]	170	0.31	0.02	0.01	Wet sawing bridge deck
16	Walk behind	9.0[A,M]	275	0.30	0.02	0.01	Wet sawing old pavement
17	Walk behind	1.7[P]	271	0.43	ND	ND	Wet sawing old pavement
18	Walk behind	9.0[A,M]	230	0.93	0.10	0.05	Wet sawing old pavement
19	Walk behind	1.7[P]	231	0.89	(0.05)	(0.02)	Wet sawing old pavement
20	Walk behind	9.0[A,M]	261	0.49	0.05	0.03	Wet sawing old pavement
21	Walk behind	9.0[A,M]	112	1.4	(0.10)	(0.02)	Wet sawing old pavement
22	Walk behind	1.7[P]	369	0.72	(0.03)	(0.02)	Wet sawing old pavement
23	Walk behind	9.0[A,M]	383	0.27	0.01	0.01	Wet sawing old pavement
24	Walk behind	1.7[P]	383	0.32	ND	ND	Wet sawing old pavement

[P]denotes personal sample.
[NC]Denotes no cyclone.
[A]Denotes area sample.
[ND]Denotes not detected.
[M]Denotes metal cyclone.
( )Result is between LOD and LOQ.

could be poured (see Figure 8). This operation consisted of two workers operating two concrete saws to saw blocks of concrete pavement. Each of the saws was equipped with a water supply that provided water to the diamond-tipped saw blades. For each saw, water was obtained from 725-gallon water tanks mounted on trucks. The water source for the two saws was under pressure from 3.5 and 4.0 horsepower water pumps. The workers did not use respirators.

Asphalt/Concrete Milling

Table VI summarizes data obtained during two shifts of asphalt milling. This operation consisted of three workers operating an asphalt mill to remove old asphalt from an interstate highway (see Figure 9). This machine operates similarly to the continuous mining machines used in coal mining with a horizontal drum studded with carbide bits and a water spray system to wet down dust. The mill is set to remove a predetermined depth of asphalt or concrete. For the operation reported here, the entire thickness of asphalt was removed from the underlying concrete pavement, thereby abrading the concrete surface in the process. The operator spent almost all of his time on top of the mill in the open. A laborer spent his time walking alongside the machine, as did the foreman. None of the workers used respirators.

Although respirable dust was found in the breathing zone of the mill operator during both shifts, quartz was not detected. On both days, elevated levels of respirable quartz were found in the breathing zone of the laborer. During the first shift (samples 1–6), the 8-hour TWA for respirable quartz dust was 0.36 mg/m^3. This concentration is over 7 times the NIOSH REL of 0.05 mg/m^3. During the second shift (samples 7–11), the 8-hour TWA for

TABLE VI
Asphalt/concrete milling

	Sample location	Flow rate L/min	Sample time min	Resp. dust mg/m^3	Resp. quartz mg/m^3	8-hr TWA quartz mg/m^3
1	Mill oper.	1.7^P	505	0.22	ND	ND
2	Laborer	1.7^P	504	2.9	0.34	0.36
3	Area 1, belt	1.7^A	516	1.3	0.05	0.05
4	Area 1, belt	1.7^A	516	2.0	0.13	0.14
5	Area 1, belt	1.7^A	516	2.6	0.22	0.24
6	Area 2	$9.0^{A,M}$	511	0.27	(0.01)	(0.01)
7	Mill Oper.	1.7^P	213	0.39	ND	ND
8	Laborer	1.7^P	202	3.0	0.23	0.10
9	Area 1, belt	1.7^A	223	1.4	(0.03)	(0.01)
10	Area 1, belt	1.7^A	223	1.7	(0.05)	(0.02)
11	Area 1, belt	1.7^A	223	1.7	(0.05)	(0.02)

^{P}Denotes personal sample.
^{NC}Denotes no cyclone.
^{A}Denotes area sample.
NDDenotes not detected.
^{M}Denotes metal cyclone.
( )Denotes result is between the LOD and LOQ.

respirable quartz dust was 0.10 mg/m^3, or twice the NIOSH REL. During the first shift, the investigators found 8-hour TWA respirable quartz concentrations ranging from the REL to over 4 times the REL at Area 1 above the conveyor belt. During the second shift, quartz was detected in the Area 1 samples, although at levels too low to quantify. The Area 2 sample during the first shift (sample 6) located on the top of machine (front end) also detected quartz at a level too low to quantify.

The results show that the laborer walking beside the machine was being exposed to respirable quartz at levels above the NIOSH REL and the OSHA PEL. The mill was provided with water from a water truck. During these types of operations maintenance of the water spray system is essential to assure that it is working as intended. Possible problems may include spray nozzle misalignment or water not being provided at high enough pressure. Dust may leak out the sides of the machine, and

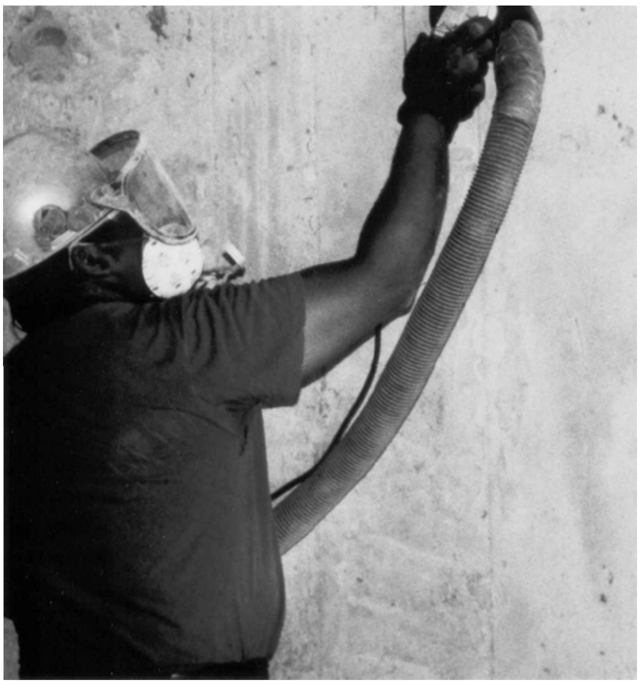

FIGURE 5
Local exhaust used on a concrete grinder with four-inch disk.

FIGURE 6
Micro-mini vacuum.

FIGURE 7
Hand-held gasoline powered concrete saw.

FIGURE 8
Walk-behind concrete saw with water truck.

therefore may require additional water sprays. An additional water spray may be needed at the conveyor belt. Care should be taken to insure that water is always provided to the drum while in operation. The mill should be shut down if it runs out of water before the water truck can return with a new load.

DISCUSSION/CONCLUSION

General Conclusions

Excessive respirable quartz concentrations can and do exist at construction projects where concrete is disturbed. In the 1970s, the problem of concrete dust generation, exposure, and silicosis was recognized and documented in France.[13–17] Still, use of prevention methods and controls for concrete dust are sparse 30 years later in the United States. When these surveys began it was common for the construction company official involved to state that they had never heard of silicosis or that they did not know that there was anything in the dust generated from concrete that could be harmful. Much still needs to be done to raise this issue within the construction industry and among construction equipment and tool manufacturers to find suitable means of controlling or preventing respirable dust generation. Power tools and equipment used to disturb silica-containing materials must be designed to allow construction workers to operate them safely. Contractors need to use dust controls capable of removing respirable dust on any mechanical device that disturbs concrete

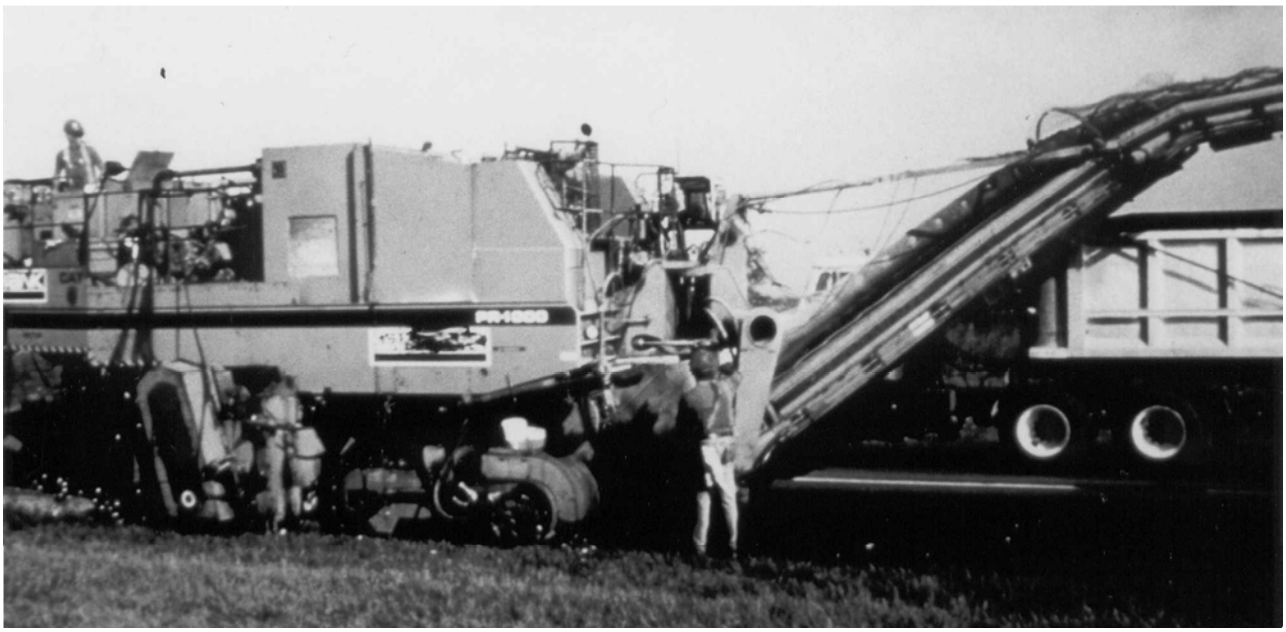

FIGURE 9
Asphalt/concrete mill.

and should periodically obtain dust samples of their operations to ensure the controls are working adequately.

Abrasive Blasting of Concrete

Abrasive blasting should only be performed by well-trained and well-equipped workers. Respiratory protection devices should never be altered and should only be used in a manner consistent with their NIOSH certification. They should always be used within a comprehensive respiratory protection plan and should be selected to provide adequate protection for the environmental conditions for which they are used. Means of eliminating the need to abrasive blast concrete should be developed. Industry must remember that whenever concrete or other masonry is abrasive blasted that a silicosis hazard will exist regardless of the abrasive used.

Concrete Drilling

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. Appropriate respirators may still need to be used.

Concrete Grinding

Wetting the surface of concrete before surface grinding greatly reduces the amount of respirable dust generated. Pneumatic grinders should be used instead of electric-powered grinders if water is the method of control. Local exhaust of the dust generated is possible, but care must be taken to select a system that is capable of doing the job and is acceptable to the workers. These systems must be continuously maintained. Appropriate respirators may still need to be used, particularly in enclosed areas.

Concrete Sawing

Systems using water on the saw blade greatly reduce the amount of respirable dust generated. Local exhaust systems are needed for operations where the presence of water causes production and/or safety problems, but may be difficult to find. Dust control systems must be continuously maintained. Appropriate respirators may still need to be used, particularly in enclosed areas.

Asphalt/Concrete Milling

Mills use water sprays to provide water to the cutting device. The water spray system must be maintained and always used. Additional water may be required for transfer points on conveyor belts. If a mechanical sweeper is used after the mill has made the cut, water must be used on the brush. Appropriate respirators may still need to be used.

Discussion, The Future

The Federal Highway Administration (FHA), in its annual report to Congress, estimates the average annual investment requirement for the years 1998–2017 to maintain United States highways and bridges to be $56.6 billion.[18] They also estimate the cost to improve highways and bridges to be $94.0 billion annually for the same time period; however, federal, state, and local highway and bridge capital outlay totaled only $48.7 billion in 1997.

This report also estimates that:

> *In 1997, 41.3 percent of measured roads were in very good or good condition, 52.1 percent were in fair or mediocre condition and 6.6 percent were in poor condition.*

And:

> *In 1998, 29.6 percent of our Nation's bridges were deficient. Of the total number of bridges, 16.0 percent were structurally deficient while 13.6 percent were functionally obsolete. In urban areas, 32.5 percent of bridges were deficient, while in rural areas 28.8 percent were deficient.*

This report also states:

> *Based on the conditions and performance of the highway system as of 1997, the backlog of cost-beneficial highway investments is estimated to be $166.7 billion. The backlog of bridge investments is estimated to be $87.3 billion in 1997.*

Therefore, it is reasonable to expect that billions of dollars of additional concrete work will be done on our bridges and highways in the years to come. This poses a challenge to all who have an interest in this type of work being performed in the safest and most healthful way possible.

Limitations

The work presented here is not a comprehensive assessment of each and every quartz hazard present or possible at construction sites; however, this data should prove useful to industrial hygienists and health professionals in identifying quartz hazards at construction sites involving concrete work, and in planning air sampling at such sites.

RECOMMENDATION

Emphasis should be placed on eliminating quartz dust exposures through process changes and dust control technology. Tools and equipment should be designed to do the job they are intended to do without generating hazardous levels of quartz dust. NIOSH has published recommendations for preventing and reporting silicosis, which should be referred to.[2,7,19,20]

NIOSH recommends the following measures to reduce exposures to respirable crystalline silica in the workplace and to prevent silicosis and deaths in construction workers.[7]

1. Recognize when silica dust may be generated and plan ahead to eliminate or control the dust at the source. Awareness and planning are keys to prevention of silicosis.
2. Do not use silica sand or other substances containing more than 1 percent crystalline silica as abrasive blasting materials. Substitute less hazardous materials.
3. Use engineering controls and containment methods such as blast-cleaning machines and cabinets, wet drilling, or wet sawing of silica-containing materials to control the hazard and protect adjacent workers from exposure.
4. Routinely maintain dust control systems to keep them in good working order.
5. Practice good personal hygiene to avoid unnecessary exposure to other work site contaminants such as lead.
6. Wear disposable or washable protective clothes at the work site.
7. Shower (if possible) and change into clean clothes before leaving the work site to prevent contamination of cars, homes, and other work areas.
8. Conduct air monitoring to measure worker exposures and ensure that controls are providing adequate protection for workers.
9. Use adequate respiratory protection when source controls cannot keep silica exposures below the NIOSH REL.
10. Provide periodic medical examinations for all workers who may be exposed to respirable crystalline silica.
11. Post warning signs to mark the boundaries of work areas contaminated with respirable crystalline silica.
12. Provide workers with training that includes information about health effects, work practices, and protective equipment for respirable crystalline silica.
13. Report all cases of silicosis to state health departments and OSHA.

DISCLAIMER

Mention of company or product names does not constitute endorsement by the Centers for Disease Control and Prevention (CDC).

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