Industrial Hygiene Survey of Respirable Crystalline Silica Dust Exposure in the Ready-Mixed Concrete Industry

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Overview

As part of the U.S. Department of Health and Human Services initiative, "Health People 2000," the National Institute for Occupational Safety and Health (NIOSH) is investigating respirable crystalline silica exposure in industries where silica is a constituent material. Ready-mix concrete was identified as an industry to investigate because of the potential for respirable crystalline silica exposure from the silica sand which comprises 10%-20% of concrete.

The Occupational Safety and Health Administration's Integrated Management Information System (OSHA's IMIS) listed 64 instances of personal and/or area sampling for respirable silica dust at ready-mixed concrete plants (SIC[1] 3273) between September 1980 and December 1993. Fourteen (22%) were listed as measuring above the OSHA Permissible Exposure Limit (PEL) for respirable crystalline silica. The exposures measured ranged up to 7 times the PEL.

As a pilot project, six local ready-mixed plants were contacted and site visits arranged to learn how extensively NIOSH should investigate the silicosis potential in the industry. Personal and area sampling for respirable dust was conducted to gauge exposures to respirable crystalline silica. Area samples were collected at areas with the highest visible dust, which was generally below the loading point for the cement component. Personal samples were collected for employees who were willing to participate.

Dust concentrations were calculated by weighing the dust collected on the filters for personal and area samples. Filters with significant weight gain were submitted for crystalline silica analysis. None of the airborne dust samples contained enough crystalline silica for a quantitative measurement. Two of these dust samples had a "detectable" but not a "quantifiable" amount of crystalline silica. Although most of the measurements were below detectable levels during our survey, day-to-day variability in work practices and weather conditions could produce higher levels of exposure. The presence of crystalline silica in two airborne dust samples suggests a "potential" for higher exposures. Road dust from around the plant's lots was the only apparent source of respirable crystalline silica. Operators might consider wetting-down dusty roadways to suppress potential exposures on their properties.

Introduction

NIOSH has undertaken this study to investigate respirable crystalline silica exposure in the ready-mixed concrete industry. Crystalline silica occurs in three distinct types -- quartz, cristobalite, and tridymite, with quartz being the predominant type of crystalline silica found at most workplaces. Cristobalite and tridymite may be somewhat more potent than quartz in causing silicosis[1]. Cristobalite and tridymite are formed from quartz when it is exposed to high temperatures (1470 and 870 degrees centigrade, respectively). These two forms of crystalline silica are not dealt with for the purposes of this investigation, since they usually occur only in the volcanic rock of California, Colorado, and Mexico[2].

The central ingredients in concrete have been the same since 1824, with one ingredient being silica sand[3]. NIOSH has attempted -- through this investigation -- to learn the extent of employees' exposure to airborne dust containing respirable crystalline silica. This pilot study examined six ready-mix operations to gauge employee exposures to respirable crystalline silica.

Each plant survey included the following:

1) Initial telephone contact with management to introduce NIOSH and the investigators, explain the purpose of this study, and arrange a date and time for a plant visit;
2) Plant tour to become acquainted with the process, identify dusty locations for area sampling, and collect personal samples for the employees who work around the plant all shift;
3) Conduct screening sampling to evaluate potential exposures to respirable crystalline silica dust.

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[1]Standard Industrial Classification

The general procedure for operation of a ready-mix concrete plant can be outlined as follows:

The ingredients (sand, gravel, Portland cement)[2] are loaded into bins atop the plant by yard workers operating heavy equipment. The proper mix is identified for each load, and a mixer truck backs under the loading chute. The sand, stone, and (most of the) water proportion are weighed, loaded into the truck, and mixed. Then the Portland cement (and fly ash, if used) are added, along with any admixtures to be included. Usually, that mixer truck will pull away from the loading point while the load mixes thoroughly, and another mixer truck backs into position below the chute. Very often, the driver of the truck that just left the loading point will wash off his truck while he's waiting for the load to mix thoroughly, before checking the mix and delivering the order.

Evaluation Criteria and Toxicology

EVALUATION CRITERIA DISCUSSION:
The evaluation criteria for cement and respirable crystalline silica are shown in Table 1 (next page). The present project concerned itself primarily with respirable crystalline silica. The other agents in Table 1 have been included to furnish additional information on related substances.

These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week, for a working lifetime without experiencing adverse health effects. It is important to realize that not all workers will be protected from adverse health effects by keeping their exposures below these levels. A small percentage may experience adverse health effects because of individual susceptibility, pre-existing medical conditions, or hypersensitivity. In addition, even if the occupational exposures are controlled at the levels set forth in Table 1, some hazardous substances may act in combination with other work-place exposures, the general environment, or with medications or personal habits of the worker to produce adverse health effects. Combined effects are not considered in these evaluation criteria, and these criteria may change over the years as new information becomes available.

Table 1: Evaluation Criteria

Agent	NIOSH REL[3]	OSHA PEL
Portland cement	5.0 mg/M^3[4]	5.0 mg/M^3
calcium oxide	2.0 mg/M^3	5.0 mg/M^3
respirable quartz	0.05 mg/M^3	$\frac{10 \text{ mg/M}^3}{\% \text{ silica} + 2}$
respirable dust	none established	5.0 mg/M^3

CEMENT / CALCIUM OXIDE TOXICOLOGY DISCUSSION:
Most of the ingredients in cement are relatively benign. However, cement does contain calcium oxide which could present a health hazard[4]. Calcium oxide is hygroscopic (which means it readily takes up

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[2]Some plants also use fly ash (a by-product of coal-fired power plants). Admixtures, less than 1% of the mix, are also added to change the wet and/or hardened properties of the concrete.

[3]Recommended Exposure Limit

[4]milligrams analyte per cubic meter of air

water). When cement dust is inhaled, it reacts with the moisture on the lining of the airways into the lungs and forms calcium hydroxide which is a strong base (pH 12-13). Plant workers and drivers should avoid inhaling this cement dust, as the strong base formed when the dust combines with the moisture on the airway walls could damage those body tissues.

SILICOSIS TOXÍCOLOGY DISCUSSION: Each living cell in the body requires a continuous supply of oxygen. Human lungs are designed to furnish the bloodstream with oxygen to meet these needs. In the course of an 8-hour day of moderate work, a person breaths about 300 cubic feet of air. In the respiratory system, the bronchi divide and subdivide, again and again. At the end of each airway are air sacs, called alveoli, which resemble tiny bunches of grapes. The alveoli are where the gas exchange (oxygen in and carbon dioxide out) takes place for the bloodstream. There are about 300 million alveoli in a human lung. The combined surface area of these alveoli averages about 300 ft^2 at rest and 1000 ft^2 at full inspiration.[5]

Normal eyesight can detect particles as small as 50 micrometers in diameter, but particles must be 10 micrometers or less in diameter before they are considered respirable (capable of being inhaled into the alveolar region of the lungs)[6]. Most of the solid particles that deposit in the alveolar region are engulfed by macrophages (mobile cells that capture foreign particles).[7] When workers are exposed to dust containing crystalline silica particles small enough to be inhaled into the alveolar region of the lungs, then the lung tissue may react by developing scar tissue, or fibrotic nodules, around the trapped silica particles. This fibrotic condition is called silicosis. Freshly fractured silica, like the dust from sandblasting, appears to produce a more severe lung reaction than silica dust that is not freshly fractured. This factor may contribute to the development of acute and accelerated forms of silicosis among workers in occupations such as sandblasting and other work involving exposure to freshly fractured silica.[8]

Acute silicosis occurs where exposures are extremely high and can cause symptoms to develop within a few weeks to 5 years. **Accelerated silicosis** can develop after 5 to 10 years of exposure to high levels of respirable crystalline silica. With so many alveoli available for oxygen exchange, the lungs may adapt to some exposure to respirable crystalline silica. However, when small amounts are inhaled regularly over a period of 10 or more years, a condition called **chronic silicosis** may result.[9]

Although the following description greatly simplifies the biological mechanism responsible for the development of silicosis, such a description may help some readers understand the potential effects of exposure to respirable crystalline silica:

Exposure to respirable crystalline silica could be compared to breathing microscopic shards of glass. The lungs have defense mechanisms to deal effectively with some of this material. Scavenger cells in the lungs, called "macrophages", may actually engulf these tiny particles and carry them out of the lungs. However, over time the lungs may be exposed to more material than they can handle, and some lung damage occurs. The scavenger cells (macrophages) may also be killed by the silica particles, so these cut up macrophages, add to the lung burden, and may produce additional damage. Although the immediate lung damage may heal, over time the scar tissue formed will reduce the surface area available for breathing, and through decreased flexibility, will make it more difficult to inhale and exhale. Over the years, all those little scratches can lead to silicosis. Early signs of silicosis include shortness of breath, fever, and cyanosis (bluish skin). Infections often complicate silicosis, because the macrophages that fight other diseases too, are overwhelmed with silica dust and less able to protect against mycobacteria and fungal organisms.

Methods and Findings

Personal and area sampling were conducted to gauge potential exposures to respirable crystalline silica. The sampling included respirable dust samples along with bulk samples of the cement, sand, and fly ash (where used). The respirable dust samples were collected in dusty areas around the plants, according to NIOSH Method 7500. Personal samples for respirable dust were also collected by this method for plant employees who were willing to participate.

When the gravimetric analysis demonstrated sufficient dust weight on the filter (0.05 mg), those filters were submitted for quartz analyses using x-ray diffraction according to NIOSH Method 7500, with minor modifications[5]. Three-pound bulk samples of sand were collected from the sand piles at three of the sites visited, and sieve analyses were requested to learn the percent of the material that was of respirable size (smaller than 10 micrometers) on delivery to the ready-mix plants [10]. Twenty-five (25) micrometers was the smallest sieve that would pass enough of the material to quantitate, and even then the weight percentages (see Table 2) were much less than one percent.

Table 2: Bulk Sample Analyses

Sample Number indicates source facility	Weight % < 25 Micrometers	Quartz Percent	Cristobalite Percent
cement 1		ND - None Detected	ND
sand 1	0.1%	39%	ND
sand 1a		74%	ND
sand 1b		52%	ND
sand 1c		50%	ND
sand 1d		53%	ND
cement 2		ND	ND
sand 2		60%	ND
cement 3		ND	ND
sand 3		50%	ND
cement		ND	ND
sand 4	0.2%	67%	ND
flyash 4		1.6%	ND
sand 5	0.2%	60%	ND
cement 5		1.6%	ND
flyash 5		ND	ND
sand 6		58%	ND
cement 6		ND	ND

Smaller bulk samples of sand, cement, and flyash were collected from all six plants surveyed and analyzed to determine the percent of silica in each. These results are also shown in Table 2.

The analytical method for the respirable dust samples requires a minimum amount of silica to be present in order to state with certainty that it was present in the sample. The Limit of Detection is 0.015 mg . Additional silica material is required in the sample in order to state quantities. The Limit of Quantitation is 0.030 mg.

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[5]a) filters were dissolved in tetrahydrofuran rather than being ashed in a furnace, and b) standards and samples were run concurrently and an external calibration curve was prepared from the integrated intensities rather than using the suggested normalization procedure.

Based on visual observation of ready-mix plants visited during this study, the dustiest area was the loading point as the cement ingredient was being added. As shown in Table 2, only one sample of cement was found to contain even a small amount of silica. From these analyses, it is likely that a significant respirable crystalline silica exposure does not occur at the loading point.

Personal and area respirable dust sample data are shown in Table 3 (next page). Exposure data given as ND indicates the exposure was below the Limit of Detection - None Detected. Exposure data given in brackets indicates that the value falls between the Limit of Detection and the Limit of Quantitation. This means that although silica was found in the sample, there was not enough for the analytical laboratory to say exactly how much was present. The samples which did not contain sufficient dust weight to proceed with the silica analysis are not reported in Table 3.

Material Safety Data Sheets (MSDS)

During the course of this investigation, the surveyors requested copies of the Material Safety Data Sheets (MSDS) which these ready-mixed companies furnish to acquaint their downstream users with the hazards associated with concrete. One company in our survey provided a MSDS on freshly mixed unhardened concrete, and several companies offered to furnish MSDSs on the constituent ingredients in concrete; but generally speaking, the companies surveyed did not have a MSDS on their product which would meet the requirements of the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard, 29 CFR 1910.1200 (g)(2).

Noting this, an effort was made to learn how widespread the deficiency is in the industry as a whole. To find out, 50 of the 600 ready-mixed companies listed in the Thomas Register[11] were randomly selected and contacted with a request for a copy of their MSDS on concrete. A breakdown of the findings is as follows:

- 20 companies claimed to have a MSDS and promised to send a copy
  (10 companies sent a copy, 10 were not received)
- 18 companies admitted that they did not have a MSDS on their product
- 4 companies were unsure if they had a MSDS on their product and none was received
- 6 companies were no longer (or never were) in the concrete business
- 2 companies were not contacted in 4-6 attempts

Table 3: Respirable Crystalline Silica Dust Sampling Data

Field Sample No. (plant #)[6]	Sample type	Sample time (minutes)	Respirable dust weight (mg)	Resp. dust conc. (mg/M^3)	Silica weight (mg)	Resp. silica conc. (mg/M^3)
22684 (4)	yard worker (personal)	120	0.07	0.35	ND	ND
22689 (4)	loading point (area)	65	0.06	0.55	ND	ND
22698 (4)	yard worker (personal)	159	0.15	0.56	ND	ND
22701 (4)	lab room (area)	234	0.14	0.35	ND	ND
22690 (1)	loading point (area)	306	0.2	0.38	ND	ND
22692 (1)	yard worker (personal)	160	0.07	0.26	ND	ND
22700 (1)	yard worker (personal)	302	0.23	0.46	[.01][7]	[0.02]
22695 (3)	loading point (area)	240	0.06	0.15	ND	ND
22696 (3)	yard worker (personal)	250	0.06	0.14	ND	ND
22685 (2)	yard worker (area)	135	0.03	0.13	[.02]	[0.09]

The National Concrete Association was contacted with a request for a MSDS on concrete. The organization furnished one that was as good and complete as any of the ten submitted by the earlier calls, but it too was found to be deficient when compared to the requirements of the Hazard Communication Standard. In order to fill this void, a MSDS was prepared and a copy is appended to this report.

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[6]Some samples did not contain enough dust weight for the analysis to proceed to determining silica content, and those companies' (5 and 6) data are not reported in Table 3.

[7]Weights expressed in brackets indicate that the value reported was between the Analytical Method's Limit of Detection and Limit of Quantitation.

Conclusions and Recommendations

By observation, the dustiest concentrations at ready-mixed concrete plants are generated for brief periods of time at the loading point during the addition of the cement ingredient. If workers need to occupy this area during loading operations, NIOSH recommends that additional sampling be undertaken to characterize exposures to this cement dust. If potential exposures are found to be near or above the NIOSH REL, then the delivery system should be upgraded with engineering controls to eliminate or reduce the exposure. If exposures near the REL cannot be eliminated or reduced sufficiently and workers are required in the area during loading operations, prudent occupational hygiene practice would require that drivers, yard workers, or other personnel needed in the area during this operation, wear appropriate respiratory protection or otherwise avoid inhaling the cement dust. This dust quickly reacts with the moisture on the linings of the airways to form calcium hydroxide, which is a strong caustic agent. Since cement dust may damage the tissues it contacts, drivers and other workers in the area should be apprised of the hazard and encouraged to avoid this exposure.

Additional sampling could also be undertaken to characterize yard workers' and other employees' exposures to respirable crystalline silica dust. If exposures are near or above the NIOSH REL, steps should be taken to reduce or eliminate them. The best method of eliminating these dust exposures might be to wet down the travel paths for the trucks and other heavy equipment which operate around the plants, especially on days when the dust is visibly disturbed and airborne. Respirable dust is too small for the human eye to detect, but when dust is visible, it follows that respirable-sized particles are probably present in the air too. Much of the material lying on the surfaces of these lots probably contains respirable crystalline silica.

If further sampling indicates need(s) for respiratory protection, the employer should institute a respirator program in accordance with the OSHA respirator standard, 29 CFR 1910.134. A copy of the standard is appended to this report.

According to the Hazard Communication Standard, companies are required to furnish an MSDS to their customers with the initial shipment and with the first shipment after a material safety data sheet is updated[12]. Accordingly, NIOSH would recommend that ready-mixed concrete suppliers provide Material Safety Data Sheets along with their products. A sample Material Safety Data Sheet for concrete is appended to this report. The most practical method of furnishing a MSDS (noticed during this investigation) was re-printing it on the reverse of the delivery tickets furnished with all orders.

References

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3. Kosmatka SB [1988]. Design and control of concrete mixtures. 13th ed. Skokie, IL: Portland Cement Association, pp.12-14.

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10. Olishifski JB [1979]. Fundamentals of industrial hygiene. Chicago, IL: National Safety Council, p.26.

11. Thomas Register [1994]. Thomas Register of American manufacturers and Thomas register catalog file: Vol. 4, Products and Services Section. New York, NY: Thomas Publishing Company, pp. 6871-6874.

12. CFR [29 CFR 1910.1200(g)] Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Example
Material Safety Data Sheet
(MSDS)

I. PRODUCT IDENTITY:

Portland Cement Concrete

II. EMERGENCY AND FIRST AID PROCEDURES:

SKIN CONTACT -- Wash skin with large amounts of soap and clean water. For minor irritation, apply a lanolin-containing cream to skin after washing. Contact a physician if persistent or severe irritation or discomfort occurs.
EYE CONTACT -- Contact a physician immediately. Flush eyes with large amounts of clean water for at least 15 minutes.
INGESTION -- Due to the nature of this material, it is unlikely that it will be ingested. If this does occur, remove individual from area. Two or three glasses of milk or water should be provided to dilute the stomach contents, if the individual is conscious. Do not induce vomiting. Contact a physician or Poison Control Center.

III. HAZARDOUS INGREDIENTS:

Concrete is a mixture of inert gravel, sand, Portland cement, and water. It may also contain chemical admixtures and/or flyash. The chemical admixtures are present in quantities comprising less than 1% of the material.

The hazardous ingredients in plastic (wet) concrete cannot become airborne. However, when the water is added to the dry ingredients, it reacts with the calcium oxide in the Portland cement to form calcium hydroxide - a corrosive chemical which will irritate the eyes and skin upon contact. Concrete dust from dried Portland cement concrete may also contain hazardous ingredients in sufficient concentrations to cause skin, eye, or respiratory disease.

Chemical - Common Name	OSHA PEL	NIOSH REL	%	CAS No.
Portland cement	5.0 mg/M^3 respirable dust; 15.0 mg/M^3 total dust	5.0 mg/M^3 respirable dust; 10.0 mg/M^3 total dust	20-30	65997-15-1
calcium oxide	5 mg/M^3 total dust	2 mg/M^3 total dust	2-4	1305-62-0
sand, quartz, crystalline silica	approximately 0.1 mg/M^3 respirable dust	0.05 mg/M3 respirable dust	10-20	14808-60-7
gravel	none	none	40-50	1317-67-3

The product is delivered as a ready mixed cement mud, so there is no dust hazard present from the wet product and the OSHA PELs and NIOSH RELs generally would not be applicable at time of delivery.

IV. PHYSICAL CHARACTERISTICS:

Appearance: . . . . . grey, plastic, granular mud
Melting point: . . . . . not applicable
Boiling point: . . . . . not applicable
Specific gravity: . . . . . (water = 1) Normal range 1.5-2.9
Vapor pressure: . . . . . not applicable
Vapor density: . . . . . not applicable
Stability: . . . . . stable
Incompatible materials: . . . . . none
Hazardous polymerization: . . . . . none
Special precautions: . . . . . will harden in 2 - 8 hours
Neutralizing chemicals: . . . . . not applicable

V. FIRE AND EXPLOSION HAZARD INFORMATION:

Flash point: . . . . . not applicable
Flammable limits: . . . . . not applicable
Extinguishing media: . . . . . not applicable
Special fire fighting procedures: . . . . . not applicable
Unusual fire/explosion hazards: . . . . . not applicable

VI. SPECIAL PROTECTION AND HEALTH HAZARD INFORMATION:

Routes of Entry and Health Effects:

SKIN/EYE CONTACT: Wet ready mix concrete mud has an alkalinity level of pH12 to pH13, and so may cause irritation and alkali burns. Prolonged or repeated contact may cause allergic dermatitis in sensitive individuals. Skin contact may cause local irritation of the affected area. Pre-existing skin conditions may be aggravated by exposure.
INGESTION: Unlikely. May cause irritation.
INHALATION: Wet ready mix concrete mud does not pose an inhalation hazard. **HOWEVER, SAWING, GRINDING, CUTTING, DRILLING, OR OTHERWISE DISTURBING DRIED CONCRETE MAY CONTRIBUTE TO ELEVATED LEVELS OF AIRBORNE RESPIRABLE SILICA DUST, WHICH MAY CAUSE SILICOSIS. ALWAYS USE APPROPRIATE RESPIRATORY PROTECTION IN DUSTY ENVIRONMENTS.**

SILICOSIS:

SILICOSIS IS A PROGRESSIVE LUNG DISEASE CAUSED BY BREATHING RESPIRABLE PARTICLES OF SILICA DUST OVER A PERIOD OF TIME. INDIVIDUALS VARY IN THEIR SUSCEPTIBILITY. CHRONIC SILICOSIS MAY DEVELOP AFTER 10 OR MORE YEARS OF EXPOSURE TO CRYSTALLINE SILICA AT RELATIVELY LOW LEVELS. ACCELERATED SILICOSIS MAY RESULT FROM EXPOSURE TO HIGH CONCENTRATIONS OVER 5-10 YEARS. ACUTE SILICOSIS OCCURS WHERE EXPOSURE CONCENTRATIONS ARE THE HIGHEST AND CAN CAUSE SYMPTOMS TO DEVELOP WITHIN A FEW WEEKS TO 5 YEARS. DRY COUGH MAY BE AN EARLY MANIFESTATION OF SILICOSIS. AS THE DISEASE PROGRESSES, THE COUGH MAY BECOME MORE PROLONGED AND BE ASSOCIATED WITH SPUTUM PRODUCTION. THE MOST FREQUENTLY OBSERVED SYMPTOMS ARE UNPRODUCTIVE COUGH, DYSPNEA (LABORED OR DIFFICULT BREATHING), CHEST PAINS, AND CHANGES IN BREATH SOUNDS.

VII. PERSONAL PROTECTION AND HAZARD CONTROL INFORMATION:

Good work practices -- minimize skin contact. Use goggles or face shield when splashing is possible. Use gloves and other skin coverings to prevent contact. Clothing saturated with plastic (wet) concrete should be removed promptly to prevent continued contact with skin.
Ventilation -- not required with plastic (wet) concrete.
Respiratory protection -- not required with plastic (wet) concrete.
Personal Protective Equipment -- **EYES:** wear safety goggles or face shield. **SKIN:** wear waterproof gloves and normal work clothing covering arms, legs, and feet.

VIII. PRECAUTIONS FOR SAFE HANDLING AND USE:

Plastic (wet) concrete should be kept out of reach of children.

Plastic (wet) concrete:

--Small spills: Material will harden in 2-8 hours and can generally be removed after hardening. If removing while still wet, water may be used to dilute. Use personal protective equipment described above.

--Large spills: Notify safety personnel. Clean-up personnel need to use eye and body protection as described above.

Dried Portland cement concrete:

--RESPIRABLE DUST MAY BE GENERATED WHEN HARDENED CONCRETE IS SUBJECTED TO MECHANICAL FORCES, SUCH AS IN DEMOLITION WORK AND SURFACE TREATMENT (SANDING, GROOVING, CHISELING, CUTTING, GRINDING, ETC).

--To the extent practical, use wet methods to minimize airborne dust levels when sawing or using other concrete renovation methods.

--Wear an appropriate and approved respirator when the work generates visible airborne dust. Providing exhaust ventilation to remove the dust to an unoccupied area when sawing or using other renovation methods may also contribute to reduced dust levels.

--Persons not wearing appropriate respiratory protective equipment should be excluded from dusty areas until the demolition work has been completed and the dust has cleared.

--When clearing renovation or demolition refuse, avoid re-entraining dust. Use wet methods or a vacuum with a high efficiency filter to remove the dust.

IX. HAZARD CLASSIFICATION:

The International Agency for Research on Cancer (IARC), the National Toxicology Program (NTP), and the National Institute for Occupational Safety and Health (NIOSH) classify crystalline silica as a probable human carcinogen.

X. MSDS PREPARATION:

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For more information contact: