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Exposure Assessment for Roofers Exposed to Silica during Installation of Roof Tiles

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INTRODUCTION

Occupational exposure to silica in the construction industry has been well documented,(1–7) and respirable crystalline silica (quartz and cristobalite) has been associated with silicosis,(8,9) lung cancer,(10,11) pulmonary tuberculosis,(12,13) and airway diseases.(14,15)

These concerns prompted a local construction union to request assistance from the National Institute for Occupational Safety and Health (NIOSH) for health hazard evaluations concerning exposures to dust and silica among roofers in Phoenix, Arizona. In response to these requests, NIOSH performed field studies to evaluate roofers' exposures to silica.

Health Effects Associated with Silica Exposure

Silicosis is a disease of the lung caused by the deposition of fine crystalline silica particles (10 μm or less in diameter) in the lungs. The deposition of silica particles in the lungs triggers a chronic inflammatory response resulting in normal lung tissue being replaced with scar tissue (fibrosis). Symptoms of silicosis may include cough, shortness of breath, chest pain, early fatigue with exertion, and wheezing. Silicosis usually occurs after years of exposure (chronic) but may appear in a shorter period of time (acute) if exposure concentrations are very high. Acute silicosis is typically associated with a history of high exposures from tasks that produce small particles of airborne dust with a high silica content.(16) The International Agency for Research on Cancer (IARC) in 1996 concluded that there was "sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the form of quartz or cristobalite from occupational sources."(17) Workers diagnosed with silicosis are also at an increased risk of developing tuberculosis due to silica particles disabling the macrophages.(18) For a diagnosis of occupational silicosis, workers must have a history of exposure to respirable silica and a confirmatory test such as a chest X-ray, chest computed tomography (CT), or lung biopsy.

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Occupational Exposure Limits for Silica

When proper work practices are not followed or controls are not employed, respirable crystalline silica exposures obtained during activities involving cutting, drilling, and crushing of materials that contain silica can exceed the NIOSH recommended exposure limit (REL), the ACGIH® threshold limit value (TLV®), and the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL).[19–21] NIOSH recommends an exposure limit for quartz of 0.05 mg/m^3 for up to 10 hr as a time-weighted average (TWA) to reduce the risk of silicosis, lung cancer, and other adverse health effects. The ACGIH TLV for respirable quartz is 0.025 mg/m^3 as an 8-hr TWA to protect against pulmonary fibrosis and lung cancer.[20]

The OSHA PEL for respirable dust containing 1% quartz or more in general industry (29 CFR 1910.1000) is expressed as an equation:[21]

$$\mathrm{Respirable\ PEL}\frac{10\ \mathrm{mg/m^3}}{\%\mathrm{Silica}+2}$$

The OSHA PEL for respirable dust containing 1% quartz or more in construction (29 CFR 1926.55) is expressed as an equation:[22]

$$\mathrm{Respirable\ PEL}\frac{250\ \mathrm{mppcf}}{\%\mathrm{Silica}+5}$$

The current OSHA PEL for respirable dust containing crystalline silica (quartz) for the construction industry is measured by impinger sampling. The PEL is expressed in millions of particles per cubic foot (mppcf); however, since the PELs were adopted, the impinger sampling method has been rendered obsolete by gravimetric sampling.[23] OSHA’s compliance of-ficers apply a conversion factor of 0.1 mg/m^3 per mppcf when converting between gravimetric sampling and particle counts when characterizing construction operation exposures.[24] In this study dust concentrations are presented in mg/m^3.

Facilities and Process Description

Roofers in home construction employed by four companies (A, B, C, and D) were included in these evaluations. Spanish was the primary language for most employees. The number of employees in each company ranged from 60 to 400; the smallest company installed approximately 200 roofs per month, while the largest company installed approximately 800 roofs per month. All four companies were located in the greater Phoenix area.

The employees were organized in crews of three to five, typically consisting of a foreman, a “second man,” laborers, and drivers. The work shift was typically 6:00 a.m. to 3:00 p.m. for 5 or 6 days per week. The roof installation included three phases: (1) laying tar paper and nailing boards to hold the tiles on the roof; (2) setting the tiles by stacking them in various areas of the roof; and (3) placing the tiles individually on the roof and cutting and nailing them in place. The tiles come in various colors and can be molded to look like wood shingles. They also come in different shapes (e.g., flat, barrel-shaped, and S-shaped). At least one hand-held gas-powered cutting saw is used per crew. Generally, the foreman or the second man cuts the tiles while the laborers and drivers lay and nail the tiles in place. At some work sites, laborers and drivers were also cutting tiles if the foreman and second man were not available. Dust is generated during the cutting of tiles to fit for size at the channels and valleys on the roof, at cupolas or turrets, and at the ends of the roof. At the completion of the roof installation, a gas-powered leaf blower is used to remove dust and debris from the tiles.

MATERIALS AND METHODS

Environmental Monitoring of Respirable Dust and Silica

The sampling strategy consisted of selecting home sites each day where employees would be cutting and laying tiles throughout the day. Two or three days of sampling was conducted on workers on the roof (i.e., foreman, second man, laborers, and drivers) at each roofing operation evaluated. Bulk samples of tile dust were collected at each house to determine the silica content in the manufactured tile. The samples were analyzed for silica (quartz, cristobalite, and tridymite), using X-ray diffraction, per *NIOSH Manual of Analytical Methods (NMAM)* 7500.[(24)]

Personal breathing zone (PBZ) air samples for respirable dust were collected and analyzed according to NIOSH Method 0600.[(24)] Samples were collected on tared 37-mm, 5-μm polyvinyl chloride (PVC) filters, at 1.7 L/min using a 10-mm Dorr-Oliver nylon cyclone pre-selector with a cut point of 3.5 μm for respirable dust. In addition, the respirable dust samples were analyzed for silica content by X-ray diffraction using NIOSH Method 7500.[(24)]

For silica results between the limit of detection (LOD) and the limit of quantitation (LOQ), the minimum quantifiable concentration (MQC) was used. This was calculated from the laboratory LOQ and sample volume.

Real-Time Particulate Sampling

Real-time sampling for airborne particulates was conducted at the largest construction company (A) with an optical particle counter (GRIMM Aerosol, Ainring, Germany). The instrument operates at a flow rate of 2 L/min and can measure particle sizes ranging from 0.23 μm to greater than 20 μm. Data were integrated over 1-min intervals.

We collected one set of data each to monitor the particulates generated by three distinct events during roof tile cutting and clean-up on newly constructed houses. These events were cutting roof tiles in a roof valley, cutting roof tiles that would be used on a roof turret, and blowing tile dust off the roof with a leaf blower. Measurements were collected in the general vicinity of the worker’s breathing zone. Start and stop times for significant tasks were recorded during each sample collection period. The data collected revealed information on the mass distribution of particles, which is reported as a concentration in mg/m^3. Estimates were made of the mass median aerodynamic diameter (MMAD) and the associated geometric standard deviation (GSD) based on the integrated particle size discrimination provided by the instrument. The density of the roofing tile particulate was assumed to be 1.0 (g/cm^3).

RESULTS

Environmental Monitoring of Respirable Dust and Silica

Bulk Samples—The 12 bulk samples of tile dust contained quantifiable amounts of quartz ranging from 13%–24%; cristobalite and tridymite were not detected in any of the samples (Table I).

Personal Breathing Zone Samples for Respirable Dust and Respirable Silica— The 8-hr respirable dust concentrations ranged from 0.2 mg/m^3 to 3.6 mg/m^3, with a geometric mean (GM) of 0.92 mg/m^3. The silica (quartz) content in the respirable dust samples ranged from 9.5% to 21.7%. Twelve of the 38 samples (32%) exceeded the calculated OSHA PEL for respirable dust containing silica for the construction industry standard, and 28 of 38 samples (74%) exceeded the calculated OSHA general industry standard. Thirty-four PBZ samples (90%) exceeded the NIOSH REL (0.05 mg/m^3), and 36 samples (95%) exceeded the ACGIH TLV (0.025 mg/m^3) for respirable quartz. Any worker on the roof has the potential to be overexposed to respirable quartz. The majority of the tile cutting during the survey was done by the foreman and the second man. The laborers rarely perform tile cutting but are often in close proximity so they can lay and set the tiles. Table II lists the GM and 8-hr respirable dust and silica concentrations for the four companies.

Real-Time Particulate Sampling

During the initial evaluation at Company A, real-time particulate sampling was conducted during three separate tasks. Results are presented in Table III that summarize the total dust concentration, MMAD, GSD, and respirable mass fractions, by task. The MMAD value indicates the diameter at which half the total mass of particles is larger and half is smaller. Results indicate that approximately 11% to 17% of the particles generated during these tasks are in the respirable range. The respirable mass fractions reflect the percentage of total mass in the respirable range, less than 10 μm.

DISCUSSION

The cement tiles used in this evaluation contained crystalline silica, and workers were exposed to respirable silica concentrations above occupational exposure limits. We recommended that a control system or program be in place to prevent recurring high silica exposures. Control systems can consist of (1) substitution with tiles that do not contain silica; (2) use of engineering controls (e.g., wet cutting or use of saws equipped with local exhaust ventilation); (3) work practice changes (e.g., positioning employees during tile cutting and roof cleaning to take advantage of wind and natural dilution ventilation, or implementing employee rotation for tile cutting jobs); (4) use of a controlled stationary saw on the ground; (5) manual tile cutters that do not require the use of a power saw; and (6) personal protective equipment (PPE). NIOSH recommends substituting less hazardous materials for crystalline silica whenever feasible. In addition, appropriate respiratory protection should be used when source controls cannot keep exposures below the occupational exposure limits or in the interim until such controls are in place. Medical surveillance of exposed employees should be performed for evaluation of conditions related to silica exposure.[25]

Crystalline silica is regulated under OSHA construction standards 29 CFR 1926.55 (Gases, Vapors, Fumes, Dust, and Mists) and 29 CFR 1926.57 (Ventilation), and OSHA general industry standard 29 CFR 1910.1000 (respirable dust containing 1% silica or more). OSHA's Hazard Communication Standard (HCS) 29 CFR 1910.1200 establishes uniform requirements to ensure that the hazards of all chemicals imported, produced, or used in the workplace are fully evaluated for possible physical or health hazards, and that this hazard information is transmitted to affected employers and exposed workers. Under the HCS, OSHA-regulated businesses must follow federal guidelines concerning hazard communication and worker training.[26]

Dry cutting of cement tiles generates large amounts of dust when not controlled. Wet cutting, whether using water from a main or a portable water tank, has been shown to be the most effective method for controlling silica dust generated during sawing because, when wet, dust is less able to become or remain airborne.[27] However, the roofing companies stated that water could not be used as a control because it would stain the roof tiles and pose a slip hazard during installation. There are commercially available masonry saws with vacuum systems. A vacuum pulls dust from the cutting point through a special fitting connected directly to the saw (fixed-blade saws) or through a dust collection shroud connected to the back of the saw (plunge-cut saws). With any vacuum system, worker protection from respirable dust is only as good as the capture efficiency of the control and the filter in the vacuum; the less efficient the capture efficiency and the filter, the more respirable dust will escape the control or pass through the vacuum exhaust air. High-efficiency particulate air (HEPA) filters will allow for maximum control because they are at least 99.97% efficient when tested with fine dust (0.3 μm). However, increasing the vacuum filter efficiency can result in decreased airflow, and lower airflow can reduce the amount of dust that a system captures at the cutting wheel. A larger filter will help minimize this problem, as will using a more powerful vacuum. HEPA filters tend to be more costly; by using pre-filters, the service life of the HEPA filter can be extended. Other options for controlling dust exposures on the roof may include cutting the tile on the ground with a controlled stationary saw, or using a manual tile cutter to replace the saw.

Three of the four evaluations were conducted in January and February when temperatures were below 80°F. However, summertime temperatures in Phoenix, Arizona, can exceed 100°F, which can discourage use of PPE by the employees. One study reported that the increased temperature imposed by wearing a disposable respirator resulted in increased physiological stress (e.g., increased heart rate and blood pressure), especially at high workloads.[28] Respirator acceptance is related directly to comfort, and if comfort decreases (e.g., sweat accumulation in the respirator), then the wearer is more likely to remove the respirator when it should be worn, thus compromising worker health.[29]

Respiratory protection in the form of filtering facepiece respirators was available on the crew trucks but was observed in use by only a few employees. In this work setting, respiratory protection should be worn until engineering controls and work practices are documented to reduce exposures below the occupational exposure limits. Half-mask air-purifying respirators have an assigned protection factor (APF) of 10, which means they can be used by workers when exposures are less than or equal to 10 times the REL (≤0.5 mg/m^3). Respirators with a higher APF and which also provide some eye protection can also be considered and include a full-facepiece air-purifying respirator with N-100, P-100, or R-100 filters (NIOSH APF = 50) or a powered air-purifying respirator (PAPR) with a loose-fitting or tight-fitting facepiece and high efficiency filters (NIOSH APF = 25 for loose fitting and NIOSH APF = 50 for tight fitting). Ease of use, reuse, disposability, and safety issues must be taken into consideration when selecting respirators.

CONCLUSION

Dry cutting of cement roof tiles with hand-held saws produces large amounts of dust containing silica in the respirable size range. During these activities, silica exposures can potentially exceed occupational exposure limits. Any worker on the roof is at risk of overexposure to respirable silica. Alternative materials and engineering controls must be explored to reduce silica exposures.

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TABLE I

Silica Content in Bulk Samples of Tile Dust

Company	n	Quartz (%)
A	2	18–19
B	4	13–24
C	3	20–22
D	3	18–22

TABLE II

GM (sample size) and Range of 8-Hour Respirable Dust and Silica Concentrations

	Company A		Company B		Company C		Company D	
	GM (n)	**Range (mg/m^3)**	**GM (n)**	**Range (mg/m^3)**	**GM (n)**	**Range (mg/m^3)**	**GM (n)**	**Range (mg/m^3)**
Respirable dust[A]	0.83 (16)	0.2–2.2	0.86 (8)	0.2–1.8	1.19 (7)	0.7–3.6	0.89 (7)	0.3–2.9
Respirable silica	0.12 (16)	0.04–0.32	0.14 (8)	0.04–0.25	0.16 (7)	0.07–0.44	0.14 (7)	0.04–0.44

Note: The minimum quantifiable concentration (MQC) for respirable silica was 0.04 mg/m^3. Two of the 7 results for Company C were based on partial shifts and not a typical 8-hr TWA.

[A]Range of general industry OSHA PELs for 8-hr respirable dust containing silica for Companies A, B, C, and D are 0.51–0.87, 0.42–0.67, 0.53–0.85, and 0.49–0.74 mg/m^3, respectively.

TABLE III

Task-Based Characterization of Particulate Matter for Company A

Task	Total Dust (mg/m^3)	MMAD, μm (GSD)	Respirable Mass Fraction (%)
Cutting roof tiles in a roof valley	100	9 (2.4)	17
Cutting roof tiles to be used on a roof turret	107	9 (2.3)	15
Blowing tile dust off roof with leaf blower	6	13 (2.7)	11