Health Considerations for Workplace Exposure to Silica

(Adapted from *Special Emphasis Program for Silicosis*, U.S. Department of Labor, OSHA)

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Background: Crystalline silica and silicosis

Crystalline silica is a ubiquitous substance that is the basic component of sand, quartz and granite rock (Markowitz & Rosner, 1995). Airborne crystalline silica occurs commonly in both work and nonwork environments. Occupational exposure to crystalline silica dust has long been known to produce silicosis, a pneumoconiosis or dust disease of the lung. Activities such as sandblasting, rock drilling, roof bolting, foundry work, stonecutting, drilling, quarrying, brick/block/concrete cutting, granite operations, lead-based paint encapsulant applications and tunneling through the earth's crust can create an airborne silica exposure hazard. In addition, some recently noted exposure to crystalline silica include the following.

- Calcined diatomaceous earth can contain anywhere from <1 percent to 75 percent cristobalite (a crystalline form of silica). In addition to use as a filtering media, calcined diatomaceous earth is often used in industries such as food and beverage preparation where only food grade products and equipment can come in contact with foods or beverages being made.
- Asphalt paving manufacturing may also be a source of crystalline silica exposure, due to the mechanical formation of crystalline silica dust when sand and aggregate passes through rotary dryers. The fine dust can have significant amounts of crystalline silica, depending upon the source of the aggregate. For example, rotary drying of gravel from the Willamette River in Oregon generated dust containing approximately 7 to 12 percent quartz. The waste dust was transferred periodically by front loader, resulting in clouds of visible dust drifting to the operator.
- The repair or replacement of linings of rotary kilns found in pulp and paper mills and in other manufacturing locations, as well as the linings in cupola furnaces, are potential sources of crystalline silica exposure. This work may not be commonly seen due to the infrequency and less visible nature of the work location. Turnarounds and yearly shutdowns are the time when this work commonly occurs.
- In food processing operations where crops such as potatoes and beans are readied for market, silica overexposures have been documented in the sorting, grading and washing areas.

Geologically, quartz is the second most common mineral in the earth's crust. Quartz is readily found in both sedimentary and igneous rocks. Quartz content can vary greatly among different rock types, for example: granite can contain from 10 to 40 percent quartz; shales have been found to average approximately 22 percent quartz; and sandstones can average almost 70 percent quartz.

Silica is a general term for the compound silicon dioxide (SiO_2). Silica can be crystalline or amorphous. Different crystalline silica structures exist as polymorphs of silica and include quartz and less common forms such as cristobalite and tridymite. The latter are less stable than quartz, which accounts for the dominance of the quartz form. Quartz can exist as two subpolymorphs, α-quartz or low quartz, and β-quartz or high quartz. Of these two forms, α-quartz is more common as the β-quartz is apparently only stable above temperatures of approximately 570°C. Upon cooling, β-quartz quickly converts to α-quartz. In the literature, crystalline silica is commonly referred to as silica sand, free-silica, quartz, cristobalite and tridymite. When diatomaceous earth is subjected to pressure or is processed (calcined) at temperatures above 1,000°C, some of the amorphous silica is converted to crystalline silica in the form of cristobalite (Flynn, et al., 1991). Recent articles have documented the creation of cristobalite in "after-service" refractive ceramic fiber insulation (Ganter, 1986; Cheng et al., 1992; Bergen et al., 1994). Amorphous silica has been found to exist in nature as opal, flint, siliceous glass, diatomaceous earth and vitreous silica (Applied Occupational and Environmental Hygiene Journal, 1995).

Silicosis is one of the world's oldest known occupational diseases with reports dating back to ancient Greece. Since the 1800s, the silicotic health problems associated with crystalline silica dust exposure have been referred to under a variety of common names including: consumption, ganister disease, grinders' asthma, grinders' dust consumption, grinders' rot, grit consumption, masons' disease, miner's asthma, miner's phthisis, potters' rot, sewer disease, stonemason's disease, chalicosis and shistosis. Silicosis was considered the most serious occupational hazard during the 1930s and was the focus of major federal, state and professional attention during this time (Rosner & Markowitz, 1994). The hazard is still present more than 60 years later.

Crystalline silica is commonly found and used in the following industries:

- electronics;
- foundry;
- ceramics, clay, pottery, stone and glass;
- construction;
- agriculture;
- maritime;
- railroad (setting and laying track);
- slate and flint quarrying and flint crushing;
- use and manufacture of abrasives;
- manufacture of soaps and detergents; and
- mining.

Perhaps the most familiar use of quartz sand is as an abrasive blasting agent to remove surface coatings prior to repainting or treating. A recent alert published by the National Institute for Occupational Safety and Health (NIOSH) estimates there are more than one million American workers who are at risk of developing silicosis. Of these workers, 100,000 are employed as sandblasters (NIOSH, 1992).

In the United States, from 1968 through 1990, the total number of deaths where silicosis was reported anywhere on the death certificate was 13,744. Of these, 6,322 listed silicosis as the underlying cause of the death (Bang et al., 1995). In this study, deaths in the United States due to silicosis were primarily concentrated in 12 states (California, Colorado, Florida, Illinois, Michigan, New Jersey, New York, Ohio, Pennsylvania, Virginia, West Virginia and Wisconsin). The silica-related deaths in these 12 states accounted for 68 percent of the total silica-related deaths in the U.S. By industry, construction accounted for 10 percent of the total silicosis related deaths (Bang et al.).

Based upon the widespread occurrence and use of crystalline silica across the major industrial groups (maritime, agriculture, construction and general industry) and in consideration of the number of silicosis related deaths, the NIOSH estimates for the number of exposed workers and the health effects of crystalline silica dust exposure (e.g., pulmonary fibrosis, lung and stomach cancer), OSHA is implementing a nationwide special emphasis program to assure worker protection from overexposure to crystalline silica dust.

Health effects of silica exposure

Inhalation of crystalline silica-containing dusts has been associated with silicosis, chronic obstructive pulmonary disease, bronchitis, collagen vascular diseases, chronic granulomatous infections such as tuberculosis, and lung cancer. In general, aerosols of particulates can be deposited in the lungs. This can produce rapid or slow local tissue damage, eventual disease or physical plugging. Dust containing crystalline silica can cause formation of fibrosis (scar tissue) in the lungs (Markowitz & Rosner, 1995).

The inhalation of free crystalline silicon dioxide (SiO_2) can produce lung disease known as silicosis. Particle size, dust concentration and duration of dust exposure are important factors in determining the attack rate, latency period, incidence, rate of progression and outcome of disease. A higher attack rate and severity of silicosis is seen with heating crystalline silica-containing materials to greater than 800EC to transform SiO_2 into tridymite and cristobalite (both of which occur naturally and are also found in synthetic silica preparations). High cristobalite concentrations also result from direct conversion of diatomaceous earth following heat and/or pressure and can be found in the superficial layers of refractory brick that have been repeatedly subjected to contact with molten metal (Markowitz & Rosner, 1995).

NIOSH has classified three types of silicosis: acute, accelerated and chronic.

Acute health effects

Intense crystalline silica exposure has resulted in outbreaks of acute silicosis referred to medically as silico-proteinosis or alveolar lipoproteinosis-like silicosis. Initially, crystalline silica particles produce an alveolitis (inflammation of the gas exchange area of the lung) that is characterized by sustained increases in the total number of alveolar cells, including macrophages, lymphocytes and neutrophils. The alveolitis has been found to progress to the characteristic nodular fibrosis of simple silicosis.

A rapid increase in the rate of synthesis and deposition of lung collagen has also been seen with the inhalation of crystalline silica particles. The collagen formed is unique to silica-induced lung disease and biochemically different from normal lung collagen (Olishifski & Plog, 1988).

Accelerated health effects

Accelerated silicosis may occur with more intense exposure over five to 15 years. Fibrotic nodules are generally smaller and the massive fibrosis often occurs in the mid-zones in the lungs.

Acute and accelerated silicosis have been associated with abrasive blasters.

Chronic health effects

Chronic silicosis usually takes 20 to 45 years to develop as a result of prolonged exposure to free crystalline silica. Nodular lesions tend to form in the upper lobes. In the simple stage of silicosis, symptoms and impairment of pulmonary function are uncommon. If progressive massive fibrosis (PMF) forms from the coalescence of fibrotic nodules, the disease usually progresses, even following removal from exposure.

Symptoms of silicosis may not develop for many years. Shortness of breath with exertion is the most common symptom of established silicosis. Cough and expectoration may develop with disease progression, especially in cigarette smokers. Wheezing typically only occurs when conditions such as chronic obstructive bronchitis or asthma are also present. Significant abnormality on a chest X-ray may not be seen until 15 to 20 years of exposure have occurred.

When advanced disease and progressive massive fibrosis are present there is distortion of the normal architecture of the lung. Airway obstruction may occur from contraction of the upper lobes of the lung. Emphysematous changes may develop in the lower lobes of the lung (Schulter, 1994).

Cancer

The issue of crystalline silica exposure and cancer is a complicated one with disagreement in the literature (Lilis, 1992). In the worst case, exposure to respirable crystalline silica dust has been associated with lung cancer (Lilis, 1992; IARC, 1987; Checkoway et al., 1993; Goldsmith, 1994; Hnizdo & Sluis-Cremer, 1991; McLaughlin et al., 1992; Winter, et al. 1990). There also has been the suggestion of stomach cancer associated with ingestion of crystalline silica (Lippmann, 1995). The International Agency for Research on Cancer (IARC), in examining the carcinogenesis of crystalline silica, has published monographs regarding crystalline silica and some silicates. IARC determined there is sufficient evidence for carcinogenicity in experimental animals with limited evidence for carcinogenicity in humans and has classified silica as a 2B carcinogen (1987). IARC is in the process of revisiting the crystalline silica carcinogen issue based upon recent epidemiological studies.

Studies have demonstrated a statistically significant, dose-related increase in lung cancer in several occupationally exposed groups. Winter et al. (1990) observed the lung cancer risk for pottery workers increased with estimated cumulative exposure to low levels of silica found in potteries. Another study also found the risk of lung cancer among pottery workers was related to exposure to silica, although the dose-response gradient was not significant (McLaughlin et al., 1992). An adjustment for possibly confounding exposure to polycyclic aromatic hydrocarbons slightly raised the odds ratio for exposure to silica. This study also analyzed lung cancer risk in tin miners in China and found a significant trend of increasing lung cancer with increasing cumulative respirable silica exposure. A significant dose-response relationship between death from lung cancer and silica dust particle-years has also been demonstrated for South African gold miners (Hnizdo and Sluis-Cremer, 1991). In this study a synergistic effect on lung cancer risk was found for silica exposure and smoking. Lung cancer risk among workers in the diatomaceous earth industry has been studied by Checkoway et al. (1993). Results showed increasing risk gradients for lung cancer with cumulative exposure to crystalline silica. The authors felt this finding indicated a causal relation. Several studies have demonstrated a relationship between the degree of silicosis disability and risk for lung cancer (Goldsmith, 1994). Since severity of silicosis reflects silica exposure, this may also indicate a dose-response relationship for silica exposure and lung cancer (Checkoway et al., 1993).

Note: Due to the potential association between exposure to dust containing crystalline silica and the development of lung and stomach cancer, one may find facilities where the employer is evaluating or has evaluated this exposure using thoracic samplers. Thoracic dust is defined as that portion in inhaled dust that penetrates the larynx and is available for deposition within the airways of the thorax. Thoracic dust includes the respirable fraction. The collection of thoracic dust samples is not a method used by OSHA.

Medical protocol recommendations for exposure to crystalline silica

Medical examinations

The following are the recommended medical procedures for individuals chronically exposed to crystalline silica or for individuals who have received one or more severe acute exposures to crystalline silica.

- A baseline examination that includes a medical and occupational history to elicit data about signs and symptoms of respiratory disease prior to exposure to crystalline silica. The medical examination emphasizing the respiratory system should be repeated every five years if less than 20 years of exposure and every two years if more than 20 years of exposure. The medical examination should be repeated more frequently if respiratory symptoms develop or upon the recommendation of the examining physician.

- A baseline chest X-ray should be obtained prior to employment, with a follow-up every five years if less than 20 years of exposure and every two years if more than 20 years of exposure. A chest X-ray may be required more frequently if determined by the examining physician.

- Pulmonary function tests (PFTs) should include forced expiratory volume in one second (FEV1), forced vital capacity (FVC) and diffusion lung capacity (DLC). PFTs should be obtained for a baseline examination with PFTs repeated every five years if less than 20 years of exposure and every two years if more than 20 years of exposure. PFTs may be required more frequently if respiratory symptoms develop or if recommended by the examining physician.

- A chest X-ray should be obtained upon employment termination.

Medical management

The chest X-ray should be a chest roentgenogram (posteroanterior 14” x 17” or 14” x 14”) classified according to the 1970 ILO International Classification of Radiographs of Pneumoconiosis by a certified class “B” reader. The medical follow-up should include the following procedures.

- With a positive chest X-ray (1/0 or greater) the worker should be placed in mandatory respiratory protection or, if already wearing a respirator, the program should be re-evaluated to assure proper fit and that the elements of 29 CFR 1910.134 are being met.

- The worker should be referred to a physician specializing in lung diseases for a medical evaluation and medical monitoring as warranted by the examining physician. A written opinion from the examining physician about whether the employee has any detected condition that would place the worker at an increased risk should be provided to the employer and the employee, while specific medical findings remain confidential.

- All medical test results should be discussed with the worker by the physician.

- In accordance with 29 CFR 1910.1020, medical records shall be maintained for at least 30 years following the employee's termination of employment, unless the employee is employed for less than one year and the records are provided to the employee upon termination.

Engineering controls and other prevention techniques

Several techniques can be used to reduce employee exposure to crystalline silica. Not all can be used to abate every workplace exposure, but employers and employees should analyze each job to determine how exposure to silica can be kept as low as possible. Engineering controls and work practices that can be used to reduce workplace exposure include:

- exhaust ventilation and dust collection systems, including proper preventive maintenance;

- prevention of recirculation of dust in collectors;

- cleaning of work areas using vacuums with high-efficiency particulate air (HEPA) filters or wet-sweeping;

- proper hygiene, including wearing washable or disposable work clothes on the job and showering and changing into clean clothes at the end of the shift;

- water sprays for cleaning dust or when cutting concrete and masonry;

- use and proper maintenance of enclosed equipment cabs;

- material substitution in abrasive blasting operations;

- automatic blast cleaning machines and cabinets that allow operation from outside of the machine;

- wet drilling;

- use and proper maintenance of drill platform skirts with inside corner flaps;

- installation of air-ring seals where the drill pipe passes through the drill deck;

- raising the drill level in steps to minimize dust leakage and lowering the deck skirt after lifting; and

- use of water filters and needle valve controls for proper regulation of the water flow rate to the drill.

With the exception of sandblasting, respirators should only be used to lower employee exposures after all feasible engineering controls, administrative controls and work practices have been implemented.

During abrasive blasting operations, workers shall wear type CE abrasive blasting respirators operating in the positive-pressure mode.

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