SILICA, CRYSTALLINE (Respirable Size)*

First Listed in the *Sixth Annual Report on Carcinogens* as *Reasonably Anticipated to be a Human Carcinogen* -- changed to *Known to be a Human Carcinogen* in the *Ninth Report on Carcinogens*

CARCINOGENICITY

Respirable crystalline silica (RCS), primarily quartz dusts occuring in industrial and occupational settings, is *known to be a human carcinogen*, based on sufficient evidence of carcinogenicity from studies in humans indicating a causal relationship between exposure to RCS and increased lung cancer rates in workers exposed to crystalline silica dust (IARC 1997, Brown *et al*. 1997, Hnizdo *et al*. 1997).

Crystalline silica is an abundant and commonly found natural material. Hazardous human exposure to RCS, primarily quartz dusts, occurs mainly in industrial and occupational settings. Respirable quartz levels exceeding 0.1 mg/m^3 are most frequently found in metal, nonmetal, and coal mines and mills; in granite quarrying and processing; in crushed stone and related industries; in foundries; in the ceramics industry; in construction; and in sandblasting operations (IARC 1997).

The link between human lung cancer and exposure to RCS is strongest in studies of quarry and granite workers, and workers involved in ceramic, pottery, refractory brick, and diatomaceous earth industries. Human cancer risks are associated with exposure to quartz and crystabolite, but not to amorphous silica. The overall relative risk is approximately 1.3 to 1.5. Higher risks are found in groups with greater exposure or longer latency. Silicosis, a marker for exposure to silica dust, is associated with elevated lung cancer rates, with relative risks of 2.0 to 4.0. Elevated risks have been seen in studies that accounted for smoking or asbestos exposure, and confounding is unlikely to explain these results (IARC 1997).

Results of animal experiments have shown consistent increases in lung cancers in rats, but not hamsters, chronically exposed to RCS by inhalation. Single intrapleural or intraperitoneal injections of various forms of RCS to rats resulted in lymphomas (IARC 1997).

ADDITIONAL INFORMATION RELEVANT TO CARCINOGENESIS OR POSSIBLE MECHANISMS OF CARCINOGENESIS

RCS deposited in the lungs causes epithelial injury and macrophage activation, leading to inflammatory responses and cell proliferation of the epithelial and interstitial cells. In humans, RCS persists in the lungs, culminating in the development of chronic silicosis, emphysema, obstructive airway disease, and lymph node fibrosis. RCS stimulates (1) release of cytokines and growth factors from macrophages and epithelial cells; (2) release of reactive oxygen and nitrogen intermediates; and (3) oxidative stress in lungs. All these pathways contribute to lung disease. Marked and persistent inflammation, specifically inflammatory cell-derived oxidants, may provide a mechanism by which RCS exposure can result in genotoxic effects in the lung parenchyma. In a human study, subjects exposed to RCS had increases in sister chromatid exchanges and chromosomal aberrations in peripheral blood lymphocytes. Most cellular

---

* No separate CAS registry number is assigned to silica, crystalline (respirable size).

genotoxicity studies with quartz samples were negative; however, *in vitro* exposure to some quartz samples induced micronuclei or cell transformation in several cell types, including Syrian hamster embryo cells, Chinese hamster lung cells, and human embryonic lung cells (IARC 1997).

PROPERTIES

Silica exists as colorless or white trigonal crystals. It occurs naturally in crystalline and amorphous forms and the specific gravity and melting point depend on the crystalline form. The basic structural units of the silica mineral are silicon tetrahedra, SiO4. Slight variations in the orientation of the silicon tetrahedra result in the different polymorphs of silica; crystalline silica has seven polymorphs. In crystalline silica, silicon and oxygen atoms are arranged in definite regular patterns throughout (Parmeggiani 1983).

Quartz, cristobalite, and tridymite are the three most common crystalline forms of free silica. Quartz is by far the most common; it is abundantly found in most rock types, including granites, quartzites, and in sands and soils. Cristobalite and tridymite are found in volcanic rocks. All three forms are interrelated and may change their form under different temperature and pressure conditions. The quartz structure is more compact than that of tridymite or cristobalite (IARC 1987, 1997). Quartz melts to glass and has the lowest coefficient of expansion by heat of any known substance. Silica is insoluble in water; its solubility increases with temperature and pH, and is affected by the presence of trace metals. The rate of solubility is also affected by particle size, and the external amorphous layer in quartz is more soluble than the crystalline underlying core (Merck 1989, IARC 1997).

USE

Crystalline silica has many uses because of its unique physical and chemical properties. Commercially produced silica products include quartzite, tripoli, gannister, chert, and novaculite. Crystalline silica also occurs in nature as agate, amethyst, chalcedony, cristobalite, flint, quartz, tridymite, and in its most common form, sand (IARC 1997). Naturally occurring silica materials are classified by end use or industry. Sand and gravel are produced almost exclusively for road building and concrete construction, depending on particle size and shape, surface texture, and porosity (IARC 1987). High-purity silica sand that may be extracted from sand and gravel operations is also a major industrial commodity. Industrial quartz crystal is another major industrial classification of silica materials (USDOI 1991).

Silica sand deposits, commonly quartz or derived from quartz, are high in silica content, typically 95%, although impurities may be present up to 25%. Silica sand has been used for many different purposes over many years. In some instances, grinding of sand or gravel is required, increasing the levels of dust containing RCS. Sand with a low iron content and more than 98.5% silica is used in the manufacture of glass and ceramics. Silica sand is also used in foundry castings; lower purity sand is added to clay to form molds for casting iron, aluminum, and copper alloys. It is also used in abrasives, such as sandpaper, grinding and polishing agents, in sandblasting materials, in hydraulic fracturing to increase rock permeability to increase oil and gas recovery, as a raw material for the production of silicon and ferrosilicon metals, abrasive silicon carbide, activated silica, silica gel desiccants, and sodium silicate, and as a builder in detergents. Additional uses are as a filter for large volumes of water, such as in municipal water and sewage treatment plants, and to make silica bricks and tiles to line furnaces and pottery kilns (IARC 1997).

Extremely fine grades of silica sand products are known as flours. Silica flour, not always labeled as containing crystalline silica and often mislabeled as amorphous silica, is used industrially as abrasive cleaners and inert fillers. Silica flour may be used in toothpaste, scouring powders, metal polishes, paints, rubber, paper, plastics, wood fillers, cements, road surfacing materials, and in foundry applications (IARC 1987).

Generally, cristobalite and tridymite occur naturally together (USDOI 1989). Cristobalite is used in the manufacture of glass, refractories, abrasives, ceramics, enamels; in scouring and grinding compounds; and to decolor and purify oils (IARC 1987).

PRODUCTION

Silica used in commercial products is obtained mainly from natural sources. U.S. production of silica sand was estimated at 25.8 million tons for 1990 and 27.9 million tons for 1994 (IARC 1997). The U.S. exports only approximately 4% of its production, and for the most part, does not import significant quantities (IARC 1987).

Natural quartz crystals are mined from the minor deposits found in the U.S.; however, synthetic quartz crystals (hypothermally cultured quartz crystals) are becoming an increasingly important source of quartz production. Today, most of the high-purity quartz mined in the U.S. is in the form of lascas, the precursor material for synthetic quartz crystals (IARC 1987). In the late 1980s, cultured quartz production surpassed natural quartz mining (USDOI 1991). Estimated U.S. mining production of quartz (lascas) was 1 million lb in 1985, 1.2 million lb in 1986, and 600,000 lb in 1988 and 1989. U.S. production of high-purity quartz was 315,000 lb in 1979, decreased to 174,000 lb in 1981, and rose to 800,000 lb in 1983 (IARC 1987). U.S. imports of lascas have ranged from 52,000 lb in 1986 to 215,000 lb in 1988 (USDOI 1991).

EXPOSURE

Potential occupational exposure to RCS occurs in many occupations and industries: quarrying and mining of coal and other minerals (metals and nonmetals); stone cutting and construction; production of glass and ceramics; foundry work; sandblasting, polishing, and grinding; abrasives manufacture; abrasive blasting; boiler scaling; cement production; plastic manufacturing; refractories; road construction and repair; rubber and paint manufacture; insulation production and installation; quarrying and tunneling; scouring soap production; tile and clay production; and vitreous enameling (IARC 1987). It was estimated that approximately 3.2 million workers in the U.S. were potentially exposed to RCS (IARC 1987). The National Occupational Exposure Survey (1981-1983) estimated that 342,683 total workers, including 37,985 females, were occupationally exposed to quartz and 20,165 total workers, including 1,514 female workers, were exposed to cristobalite (NIOSH 1984).

Potential exposure to RCS has been studied in metal and nonmetal mining and milling operations. Workers in sandstone, clay, and shale, and miscellaneous nonmetallic mineral mills had the highest exposures to silica dust. Within the mills, the workers with the highest exposures were the baggers, general laborers, and personnel involved in the crushing, grinding, and sizing operations. Granite and stone industry and construction personnel are also potentially exposed to RCS. Sculptors and carvers, stencil cutters, polishers, and sandblasters had the highest potential exposures; the silica content of respirable dust ranged from 4.8 to 12.2%. RCS exposures in clay pipe factories ranged from 0.01 to 0.20 mg/m^3; 10% of 348 samples collected from glass manufacturing industries had silica concentrations at least two times the permissible exposure standards; 23 to 26% of samples from clay products and pottery industries had concentrations more than twice the exposure limits; one-third of dust samples from fibrous glass plants had concentrations of RCS in excess of 0.10 mg/m^3; levels of RCS in a ceramic electronic equipment parts plant ranged from 0 to 0.18 mg/m^3; and 23% of samples collected in iron and steel foundries had concentrations in excess of 0.20 mg/m^3 RCS (IARC 1987).

Nonoccupational exposure to respirable crystalline silica results from natural processes and anthropogenic sources; silica is a common air contaminant. Residents near quarries and sand and gravel operations are potentially exposed to RCS. A major source of cristobalite and tridymite in the U.S. is volcanic rock in California and Colorado (NIOSH 1986). Local conditions, especially in deserts and areas around recent volcanic eruptions and mine dumps, can give rise to silica-containing dust (IARC 1987).

Silica and its common forms are found in a large number of consumer products. Talc is derived from crushed rock; spackling, patching, and taping compounds for dry-wall construction are formulated from a blend of minerals including crystalline silica (IARC 1987). Silica flour is added to toothpaste, scouring powders, wood fillers soaps, paints, and porcelain (NIOSH 1986). Consumers may also be exposed to RCS from abrasives, sand paper, detergent, cement, and grouts. Crystalline silica also may be an unintentional contaminant, for example, diatomaceous earth, used as a filler in reconstituted tobacco sheets, may be converted to cristobalite as it passes through the burning tip of tobacco products (IARC 1987).

REGULATIONS

The NIOSH has a recommended exposure limit (REL) for all forms of crystalline silica of 50 µg/m^3 (TWA) to protect workers from silicosis as well as potential carcinogenicity. The NIOSH recommends that silica, crystalline quartz (respirable) be labeled a potential occupational carcinogen. The OSHA has established permissible exposure limits (PEL) for an 8-hr time-weighted average (TWA) for crystalline quartz (<0.1 mg/m^3) and crystalline cristobalite and crystalline tridymite (<0.05 mg/m^3). OSHA also regulates silica, crystalline (respirable) under the Hazard Communication Standard and as a chemical hazard in laboratories. Regulations are summarized in Volume II, Table 161.

REFERENCES

Brown, L.M., G. Gridley, J.H. Olsen, L. Mellemkjaer, M.S. Linet, and J.F.J. Fraumeni. Cancer Risk and Mortality Patterns Among Silicotic Men in Sweden and Denmark. J. Occup. Environ. Med. 39:633-638, 1997.

Hnizdo, E., J. Murray, and S. Klempman. Lung cancer in relation to exposure to silica dust, silicosis and uranium production in South African gold miners. Thorax. 52:271-275, 1997.

IARC. International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Silica and Some Silicates. Vol. 42, 39 pp. Lyon, France: IARC, 1987.

IARC. International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Silica, Some Silicates, Coal Dust and Para-aramid Fibrils. Vol. 68, 40 pp, Lyon, France: IARC, 1997.

Merck. The Merck Index, Eleventh Edition. Rahway, NJ: Merck & Co., Inc., 1989.

NIOSH. National Institute for Occupational Safety and Health. National Occupational Exposure Survey (1981-83). Cincinnati, OH: Department of Health and Human Services, 1984.

NIOSH. National Institute for Occupational Safety and Health. Occupational Respiratory Diseases. Department of Health and Human Services, 1986.

Parmeggiani, L. Encyclopedia of Occupational Health and Safety. Third (revised) Edition. Vol. 2. Geneva, Switzerland: International Labour Organization, 1983.

USDOI. U.S. Department of the Interior, Bureau of Mines. Mineral Commodity Summaries 1989. USDOI, Washington, DC, 1989.

USDOI. U.S. Department of the Interior, Bureau of Mines. Mineral Commodity Summaries 1991. 196 pp. USDOI, Washington, DC, 1991.