GOBIERNO DE ESPAÑA
MINISTERIO DE TRABAJO Y ECONOMÍA SOCIAL
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Instituto Nacional de Seguridad y Salud en el Trabajo

# Respirable Crystalline Silica

## CARCINOGENS AT WORK: Know to Prevent

## Information about the substance and where it can be found

Silica is the name given to a group of minerals, compounds of silicon and oxygen, the two most abundant chemical elements in the earth's crust. These two elements combine to make silicon dioxide ($SiO_2$) and form different minerals depending on their crystalline structure. Silica can be found in crystalline or amorphous form.

The term "crystalline" refers to the arrangement of silicon dioxide molecules in an ordered three-dimensional lattice. The arrangement of this lattice will determine the ore formed. The best-known and most commonly-used forms of crystalline silica are quartz, cristobalite and tridymite.

Quartz is the most abundant form of crystalline silica and is found in many natural environments, processes and industries. The cristobalite and tridymite forms are less abundant in nature. In industrial environments, tridymite may form if quartz is heated to temperatures above 800°C and cristobalite at temperatures above 1400°C.

Crystalline silica can be found in many rocks and sediments, usually in the form of quartz, such as sand and gravel. These aggregates, in turn, are the basis for many building materials, such as concrete or bricks. Quartz is also the basic component of glass and ceramics and is used, in the form of sand, as an abrasive agent in many processes. Table 1 lists some mineral sources along with their approximate crystalline silica content.

Crystalline silica is therefore a natural compound found almost everywhere, but, if it is not handled, it does not pose a health risk. However, when rocks and other materials containing crystalline silica are cut, crushed, drilled or used in similar industrial processes, dust particles are produced.

Some of these particles are so small (the size of the respirable fraction, that is, with a diameter <10 μm) that, when suspended in air, they can be inhaled and are able to reach the pulmonary alveoli.

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They are deposited there; they accumulate and they can cause significant damage to health.

Particles of this size are not visible to the human eye and can remain in suspension for a long time, which increases the likelihood that they will be inhaled.

**Respirable crystalline silica (RCS) consists of mineral particles composed of crystallised silicon dioxide, usually in the form of quartz or cristobalite, whose size is 10 µm or less, and which are found in suspension, usually after mechanical processing of materials containing these minerals.**

# Health effects

The main health effect resulting from the inhalation of RCS dust is the development of silicosis. Moreover, RCS dust inhalation is associated with other diseases such as lung cancer, chronic kidney disease, accelerated loss of lung function, increased risk of tuberculosis and autoimmune diseases such as rheumatoid arthritis, lupus erythematosus and scleroderma (Rice 2000), (IARC 2012), (IARC 1997).

Silicosis is a lung disease characterised by production of collagenous tissue in response to accumulation of RCS dust. It is one of the longest-known occupational diseases and has always been associated with the mining profession, although it is also associated with other industries such as smelting and tunnelling.

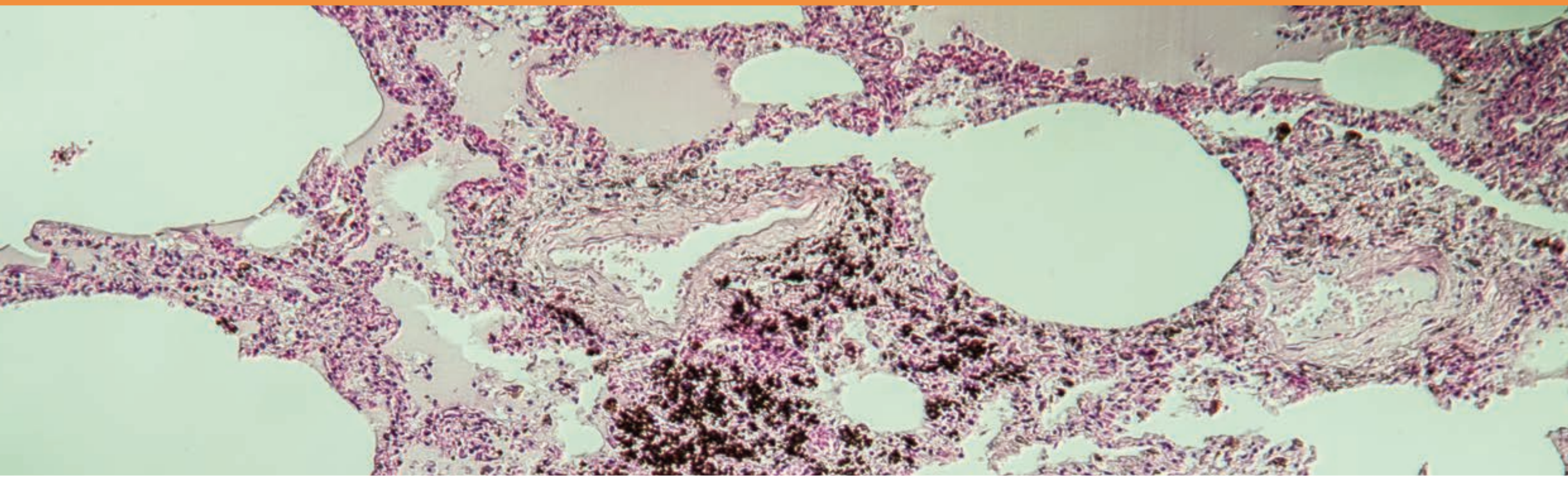
There are several types of silicosis differentiated by how the disease develops and its severity (simple chronic, complicated chronic, interstitial fibrosis, acute and accelerated). There is no effective treatment.

The most severe type of this pneumoconiosis is known as acute silicosis. It occurs after exposure to very high concentrations of RCS dust; disease progression is very rapid after short exposure periods (6 months to 5 years) and may lead to death.

**Table 1**
**Crystalline silica content of certain rocks and aggregates**

| Mineral sources | Percentage of crystalline silica |
|---|---|
| Limestone | Normally less than 1% |
| Marble | Up to 5% |
| Basalt | Up to 5% |
| Dolerite | Up to 15% |
| Granite | Up to 30% |
| Slate | Up to 40% |
| Shale | 40% - 60% |
| Gravel | Greater than 80% |
| Sand and sandstone | Greater than 90% |
| Flint | Greater than 90% |
| Quartzite | Greater than 95% |

*Source: HSE Leaflet, control of respirable crystalline silica in quarries*



Silicosis can lead to a significant loss of workers' lung capacity, which may render them unable to perform any activity, either in their personal lives or at work.

**Inhalation of RCS dust also increases the risk of developing lung cancer.**

In 2009, the International Agency for Research on Cancer (IARC) ratified the classification of crystalline silica, in the form of quartz dust or cristobalite, as a human carcinogen (Group 1). This classification is based on, among other things, the existence of sufficient evidence in humans, that is, epidemiological studies concluding that there is a correlation between inhalation of RCS dust in the workplace and an increased risk of lung cancer.

Both silicosis and lung cancer are related to continuous exposure over the years, that is, the more crystalline silica that accumulates in the alveoli over the years, the more likely it is that silicosis and lung cancer will develop.

The body's response to RCS dust exposure will also be influenced by other factors or habits such as smoking, so that there is a synergistic effect of these substances on the body, leading to other pathologies, such as COPD.

The IARC (iarc.who.int) is an autonomous agency of the World Health Organization of the United Nations. It seeks to promote international collaboration in cancer research. It runs studies that are widely recognised for their quality and independence.

## Where the exposure can take place

RCS dust, solar radiation and diesel exhaust fumes are the most frequently encountered carcinogens in the workplace and the ones to which the greatest number of workers are exposed.

This exposure can occur in work involving earth moving, for example, mining, agriculture, construction, quarrying, and other work involving mechanical operations.

On silica-containing materials or where sand is used in the production process, such as the steel and foundry industry, the glass industry, the manufacture of porcelain and ceramic products, industries or activities involving sandblasting or abrasive blasting and construction, among others.

In industries in which quartz-containing materials are subjected to high temperatures (T>1300°C), such as foundries, exposure to cristobalite is also to be expected. In recent years, a proportion of cristobalite has also been observed in artificial materials known as quartz agglomerates, which are marketed under various brand names, although in this case the material is intentionally provided due to the properties it can offer.

A non-exhaustive list of industries and activities in which exposure to RCS dust may occur, as well as the specific operations or tasks where this risk usually occurs and the material from which the RCS originates, can be found in table 2.

## Exposure assessment

Work involving exposure to respirable crystalline silica dust generated in a work process falls within the scope of Royal Decree 665/1997, on the protection of workers from the risks related to exposure to carcinogens at work; therefore, the exposure assessment and the control measures to be applied must take into account the requirements of this regulation, which also includes an occupational exposure limit (8 hour-OEL) of 0.05 mg/m$^3$ for the respirable fraction of crystalline silica dust.

According to these regulations, once the risk of exposure to this agent has been identified, it shall be eliminated or avoided, as a priority, in the conception and design phases of the activity. For those risks which cannot be eliminated, an assessment of the risks shall be performed to determine the nature, degree and duration of exposure of workers. The risk assessment will provide information about the preventive measures to be implemented to reduce exposure to as low a level as technically feasible.

For carcinogens or mutagens for which an OEL has been established has been established, the assessment of inhalation exposure is based on measuring the concentration of the chemical agent in the worker's breathing area, the weighting of the result according to the reference period, normally 8 hours, and its comparison with the established OEL.

| Table 2<br>Main activities in which occupational exposure to RCS may occur - From IARC Monograph 100-C | | |
|---|---|---|
| **Industry or activity** | **Specific operation/task** | **Source material** |
| Agriculture | Ploughing, harvesting, use of machinery | Soil |
| Mining and related milling operations | Most occupations (underground, surface, mills) and mines (metal and non-metal, coal) | Ores and associated rocks |
| Quarrying and related milling operations | Stone crushing, sand and gravel processing, monumental stone cutting and abrasive blasting, slate work, diatomite calcining | Sandstone, granite, flint, sand, gravel, slate, diatomaceous earth |
| Construction | Sandblasting of structures, buildings,<br>Road and tunnel construction<br>Excavation and earth-moving<br>Masonry and concrete working, demolition | Sand, concrete<br>Rocks<br>Soil and rocks<br>Concrete, mortar, plaster |
| Glass, including fibreglass | Raw material processing<br>Refractory installation and repair | Sand, crushed quartz<br>Refractory materials |
| Cement | Raw material processing | Clay, sand, limestone, diatomaceous earth |
| Abrasives | Production of silicon carbide<br>Production of abrasive products | Sand<br>Tripoli, sandstone |
| Ceramics, including bricks, tiles, sanitary ware, porcelain, pottery, refractories, vitreous enamels, vitreous enamels, etc | Mixing, moulding, enamel spraying and glazing, finishing | Clay, shale, flint, sand, quartzite, soil diatomaceous earth |
| Iron and steel mills | Refractory preparation and furnace repair | Refractory material |
| Silicon and ferro-silicon | Raw materials handling | Sand |
| Foundries (ferrous and non-ferrous) | Moulding and pouring (usually by shaking, vibrating or tapping)<br>Cleaning and deburring (or planing)<br>Furnace installation and repair | Sand<br><br>Sand<br>Refractory material |
| Metal industry, including metal structures, machinery, transportation equipment | Sandblasting | Sand |
| Shipbuilding and repair | Sandblasting | Sand |
| Rubber and plastics | Raw material handling | Fillers (tripoli, diatomaceous earth) |
| Paints | Raw material handling | Fillers (tripoli, diatomaceous earth, silica flour) |
| Soaps and cosmetics | Abrasive soaps, scouring powders | Silica flour |
| Roofing felt | Application of filler and granulate | Sand and aggregates, diatomaceous earth |
| Agricultural chemicals | Crushing of raw materials, handling | Phosphate ore and rocks |
| Jewellery | Cutting, grinding, sanding, polishing | Semi-precious stones or gems, abrasives |
| Dental material | Sandblasting, polishing | Sand, abrasives |
| Automovile repair | Abrasive blasting | Sand |
| Boiler cleaning | Coal-fired boilers | Ashes and concretions |

Along with the design of the sampling strategy, the first step in sampling RCS for later laboratory analysis is the choice of the most appropriate method for the purposes of the measurement, bearing in mind the specific conditions of the working environment and the materials or other substances that may be present besides crystalline silica.

Two methods for sampling and analysis have been validated by INSST:

- MTA/MA-056/06: Determination of free crystalline silica (quartz,cristobalite, tridymite) in air - Membrane Filter Method /X-Ray Diffraction
- MTA/MA-057/ A17: Determination of crystalline silica (respirable fraction) in air. Membrane filter method/ Infrared spectrophotometry

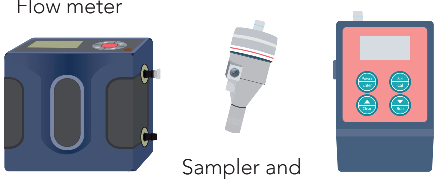
The presence of other chemical compounds, such as carbonates or other silicates, may cause interferences during the analysis. It is important to consider this possibility as it may affect the treatment of samples prior to analysis, as well as other aspects of the sampling and analysis method itself.

When it is necessary to differentiate between polymorphs of crystalline silica in a sample, for example when it is suspected that cristobalite may be present besides quartz, it is necessary to resort to the X-ray diffraction method of analysis. For this, the only currently nationally accredited laboratory is the National Institute of Silicosis (INS).

In any case, laboratories specialising in determining crystalline silica in air, in the field of industrial hygiene, can resolve all queries that may arise about the requirements to be fulfilled by the sampling equipment to obtain the adequate sampling for the purposes of measurement.

### Representativeness of the samples

Whenever a quantitative assessment of inhalation exposure to a hazardous chemical agent, a sampling strategy must be adopted to ensure the representativeness of the data obtained. This can be obtained by following the standard UNE-EN 689:2019+AC:2019 "Workplace exposure Measurement of exposure by inhalation to chemical agents Strategy for testing compliance with occupational exposure limit values"




## Controlling exposure

Exposure control or prevention measures should be prioritised according to their effectiveness. The first option should always be substitution; where this is not possible, consideration should be given to the possibility of working in a closed system.

if this is also not possible, all measures to reduce exposure to as low a level as technically feasible should be used and, finally, if the above measures are not sufficient, personal protective equipment (PPE) should be used.

## 1. Substitution

The priority measure, which is mandatory whenever it is feasible, when working with carcinogens or mutagens, is always substitution with another agent or another non-hazardous or less hazardous process. This measure is the most difficult to implement, especially when a production process is already in place, and many variables must be taken into account, but it must be planned and it is necessary to keep up to date with technological advances in each sector.

Substitution may be based on changing an agent to a less hazardous agent or eliminating or changing procedures. In any case, the new risks that may be introduced by substitution must always be assessed.

### Examples of substitution

There are experiences of replacing sand in the jeans abrasion process with a system that uses ice or laser equipment to abrade the fabric. Other minerals such as corundum, recycled glass or sodium bicarbonate are already being used for abrasion and surface treatment.

In construction, the risk can be eliminated as long as dust-generating operations are avoided. As an example, the use of BIM (Building Information Modelling) methodology has been successfully tested to predict where holes or cut-outs will be needed in the parts so that these elements are included in the parts directly in the factory, where it is easier to control exposure.

## 2. Closed system

It consists of preventing the dispersion of the agent into the air breathed by the worker by locating the process within a sealed system with air evacuation, and a system for treating and evacuating to a safe environment to prevent the agents from harming the environment or public health.

In general, this will be more feasible in industrial environments than in changing or mobile working environments such as construction sites. It is often used in stone and stone processing machinery, in equipment such as looms, edge polishing machines and abrasive blasting machines. The enclosure may be total or partial and may be combined with local exhaust ventilation system.

**Prioritisation of preventive measures for carcinogens:**

1. Substitution
2. Closed system
3. Reduction of exposure to a level as low as technically possible
4. Personal protective equipment

*Enclosure for sandblasting*

## 3. Reduction exposure to as low a level as technically possible

The aim is to implement technical and organisational measures so that exposure is reduced as much as technically feasible. This obligation implies that it is not sufficient to achieve exposure levels below the established occupational exposure limit, but rather that it is necessary to go beyond it by applying all available measures.

### Wet operations

A priority measure to be implemented, whenever possible, is to prevent the dispersion of RCS by capturing the dust generated as close as possible to the source. The most common preventive measure in many RCS-related sectors is to add water to the cutting, drilling, etc. points to capture and carry away the particles, preventing them from becoming suspended. In many tasks related to stone processing, large quantities of water are used to ensure the dust is collected and to cool the cutting elements.

When this preventive measure is used, a system and procedure for cleaning and collection of sludge must be put in place to prevent the dust from going into suspension when the sludge dries. The waste must be handed over to an authorised waste manager.

### Local exhaust ventilation

Where it is not feasible or sufficient to inject water, the dust generated at the source of the emission is usually collected using local exhaust ventilation system. The more capture systems cover or surround the emission source and the closer they are placed, the more efficient and effective they will be. It is important to correctly determine the extraction flow rate, which for RCS is usually high due to the type of dust generated. The equipment's maintenance programme must take into account clogging of the filters.

### Closed system

When working inside machinery, normal practice is to use closed cabins with high efficiency filters (HEPA, High Efficiency Particulate Air) and positive pressure inside, so that the air that the worker breathes is free of RCS dust. In these circumstances, it is very important to establish working procedures so that the worker has to leave the cabin as little as possible and, when he/she does, that he/she use respiratory PPE if necessary. In this and all other measures, training of workers is essential to ensure their effectiveness. Fixed cabins for workers, with controlled environmental conditions, can also be used in industrial environments. In these circumstances, it is

**Resources for substitution:**

More practical experiences of risk substitution or elimination can be found in the following links:

- Solutions, examples of substitution and good practice for carcinogens, from the Roadmap on carcinogens initiative.

- https://roadmaponcarcinogens.eu/solutions/good-practices/

- SUBSPORT Substitution Support Portal.

https://www.subsportplus.eu/

- OECD Substitution Toolkit Portal.

http://www.oecdsaatoolbox.org/

- INRS Substitution Fact Sheets.

http://www.inrs.fr/actualites/nouvelles-far-fas.html

advisable to have video systems at the points of the processes that need to be monitored most frequently to avoid having to leave the booth. Whether the booths are located in machinery or fixed, communication systems with the outside or with other parts of the process must also be provided as necessary.

### Segregation of zones

Another measure that can be used in industrial environments is to separate the dirtiest areas from the rest by means of rubber curtains or enclosures, so that exposure can be more easily controlled and contamination avoided.

### Nebulisation

Nebulisation has been implemented in natural stone processing workshops as a measure to control the concentration of RCS dust in the environment. Although the priority measures should be those that focus on the emitting source, this technique can be used as a complementary measure and it has been shown that, in certain activities, it can reduce workers' exposure (Montes Beneitez and Peña Loroño 2018), (NEPSI 2006).

### Resources

The examples of preventive measures are not exhaustive; each production sector has its own peculiarities and needs specific preventive measures depending on its processes and working conditions. The Guide to Good Practice for the Protection of the Health and Safety of Workers for Appropriate Handling and Use of Crystalline Silica and Products containing it which is based on the NEPSI social dialogue initiative, contains recommendation sheets on practical measures to be applied in different sectors where this risk exists. When reading this guide, it should be borne in mind that the latest version dates from 2006 and therefore the regulatory references and some of the techniques may be out of date.

Chemical Agents Control Sheets (CAQF). The INSST has translated into Spanish the fact sheets developed by the Health and Safety Executive (HSE) from its model COSHH Essentials. As part of a special series, 9 specific fact sheets have been published to control silica in quarries, which describe the preventive measures to be taken depending on the process.

### Regulatory references

Whenever carcinogenic or mutagenic agents are used, all necessary measures as laid down in art. 5.5. of the Royal Decree 665/1997 shall apply in general, these requirements are in line with the requirements of Royal Decree 374/2001 on the protection of the health and safety of workers from the risks related to chemical agents at work, which should already be complied with, adding the express mention of installing detection and warning devices in the event of situations that could generate abnormally high exposures, such as a failure in a local exhaust ventilation.

### Portable machines

On-site assembly of silica-containing elements often requires cutting, drilling and other operations with equipment that can generate and suspend RCS dust. In these circumstances it is very important to use machines and tools with built-in water supply (wet work) or local exhaust ventilation. Both systems must have appropriate flow rates and designs to maximise particle collection. In these circumstances it may be necessary to use respiratory PPE as a complementary measure.

## 4. Personal protective equipment

Respiratory protective equipment should not be used as the only preventive measure, all the above technical measures should be applied first.

However, such equipment may be necessary for certain specific operations, for example, when exiting a sealed enclosure or when performing maintenance, cleaning or adjustment operations.

The outcome of the RCS exposure risk assessment will be the basis for determining the need for personal protective equipment as well as for the selection of the most appropriate equipment. Moreover, when selecting equipment, the anatomy of the workers who will be using it must be taken into account and it is highly recommended that a fit test be performed on each person. The specific mining regulations make this test compulsory.

Equipment suitable for respiratory protection against RCS dust has a particulate protection filter (letter P, colour white), with the highest level of filtering efficiency, level 3. Any of the existing configurations on the market may be selected depending on which one suits the specific needs of each post and worker, either FFP3 self-filtering masks or masks or half masks with P3 filter.

If there is an atmosphere with insufficient oxygen concentration or other polluting gases or vapours, other equipment should be selected to protect against these risks too.

Cleaning and maintenance procedures for these PPE are as important as their proper selection and use. Manufacturers' recommendations must be strictly followed and workers must be trained to know and apply them properly. A suitable storage place for PPE must be provided.

### Regulatory references

In the mining sector, the basic legislation setting out health and safety requirements is Royal Decree 1389/1997 of 5 September 1997, passing the minimum provisions to protect the health and safety of workers in mining activities. Law 31/1995, on the Prevention of Occupational Risks, is fully applicable to these activities, as is Royal Decree 863/1985, passing the General Regulations on Basic Mining Safety Standards (RGNBSM) and its complementary Technical Instructions (ITC), which implement it. Specifically, the control of exposure to RCS dust is regulated by ITC 02.0.02 "Protection of workers against the risk of inhalation of respirable dust and crystalline silica".

*Example of one of the types of half masks for P3 filters available on the market. Source: https://www.draeger.com*

# Health surveillance

Health surveillance of workers exposed to RCS is performed according to the Specific Health Surveillance Protocol put in place by the Ministry of Health for silicosis (Health 2020). This protocol sets out, among other specifications, the criteria for determining the frequency with which medical examinations must be performed.

Carcinogens or mutagens are generally characterised by long-term effects or diseases with long latency periods. Thus, Royal Decree 665/1997 creates a right for workers who have been exposed to these agents to the extension of health surveillance beyond the end of the exposure or of the employment relationship. In the specific case of RCS exposure, the specific protocol already recommends this prolongation.

Where the cessation of exposure is due to the termination of the employment relationship, post-occupational health surveillance shall be performed through the national health system. However, where the cessation of exposure is due, for example, to a change of post (in the same company), it will continue to be the responsibility of the employer.

The report on new cases of silicosis registered at the INS in 2019 (INS 2019) warns that, in a high number of cases, the patient's initial diagnosis was complex pneumoconiosis, which could be avoided with proper health surveillance of the workers.

# Other preventive measures

In works with risk due to exposure to RCS dust generated in a work process, another series of preventive measures set out in Royal Decree 665/1997 must be complied with, such as the following:

- Personal hygiene measures (article 6).
- Measures to be taken in the event of accidental and non-regular exposures (article 7).
- Documentation-related obligations (article 9).
- Reporting to the authorities (article 10).
- Consultation, information and training of workers (articles 11 and 12).

### Regulatory references

Silicosis is an occupational disease listed in Royal Decree 1299/2006, which approves the list of occupational diseases.

In 2018, lung cancer in workers exposed to inhalation of free silica dust was also listed as an occupational disease, in Royal Decree 257/2018.

Health surveillance must be performed (art. 8 Royal Decree 665/1997):

- Before the exposure
- At regular intervals, as often as medical events dictate.
- When it is necessary because a disorder has been detected in one of the company's workers with similar exposure, which may be due to exposure to carcinogenic or mutagenic agents.

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