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Article

Investigation of the Health Effects of Workers Exposed to Respirable Crystalline Silica during Outdoor and Underground Construction Projects in Greece

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Abstract: Chronic exposure of workers to powder containing crystalline silica (SiO_2) can lead to chronic lung diseases (lung cancer, silicosis, etc.). The aim of the study was to evaluate the exposure of Greek construction workers to SiO_2 and describe their pulmonary function. The study involved 86 outdoor and underground workers. Medical and professional history was obtained, and samples were collected for the determination of SiO_2 levels. Pulmonary function tests, radiological examination and evaluation of radiographs were, also performed. During the examination of the pulmonary function, the majority of the workers were within normal range (61.4%) while the rest were diagnosed with mild (26.5%) and more severe impairment (7.2%). Working conditions (underground-outdoor) were statistically significantly related to the categorization of pulmonary function ($P = 0.038$). During radiological examination, the type of working conditions (underground-outdoor) were statistically significantly related to the categorization of these findings ($P = 0.044$). Of the 69 employees, 52 did not present findings (75.4%) and five (5) were diagnosed with findings specific to occupational diseases (7.2%). The environmental exposure to RCS (Respirable crystalline silica) was detected at 12 mg / m^3 in the workplace, which is beyond the legal

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limits. Underground workers with more than 15 years of exposure to SiO_2 may experience silicification in its chronic form compared to the workers of outdoor activities.

Keywords: Silicosis; silicon powder; crystalline silica (SiO_2); construction workers; occupational exposure; occupational exposure limit; occupational hygiene.

1. Introduction

The working environment of industries in the construction branch, both in underground and in outdoor activities, is by its nature burdened with particulate dust [1,2]. This dust is a threat to the health and safety of workers since chronic exposure can lead to serious respiratory diseases. In particular, when the dust contains free crystalline silicon dioxide special measures and precautions are required since once inhaled, the dust ceases to be inert and can cause chronic lung diseases such as silicosis, chronic obstructive pulmonary disease (emphysema) and lung cancer [1–3].

Silicon, the second most abundant element (following oxygen) in the earth's crust, is a group IV metal oxide that occurs in nature in three (3) forms: crystalline, microcrystalline (or cryptocrystalline) and amorphous (non-crystalline) [4]. The term "crystalline" that is commonly used refers to the orientation of silicon molecules (SiO_2) in a fixed configuration against a non-periodic, random molecular arrangement, designated as amorphous. The three most common crystalline forms [3 main polymorphs] of silicon that occur in the working environment are quartz, cristobalite and tridymite [2,5,6]. Quartz is the second most common mineral in the world [5].

Inhalation of Respirable Crystalline Silica (RCS) can lead to serious health effects, such as silicosis, Chronic Obstructive Pulmonary Disease (COPD), tuberculosis and lung cancer [7–11]. Respiratory diseases often occur in construction workers operating in underground excavation and tunneling constructions [12–14], as well as in outdoor ones [15]. Studies have shown that the potential exposure of construction workers to RCS exceeds that of 3 million in the European Union, 1.7 million in the US and 350 000 in Canada [3].

Silicosis is a type of pneumoconiosis caused by exposure of workers to inhaled crystalline silica powder [16]. Crystalline silicon dioxide, in the form of quartz powder or "cristobalite" and tridymite, is responsible for causing silicosis that is categorized as an occupational disease [7,8]. It is characterized by the appearance of pulmonary fibrosis and silica nodules. The development - progression of the disease continues even after the interruption of the exposure. There are three (3) forms of the disease: Chronic, acute and lightning stroke [12,13].

Cancer is the first cause of work-related deaths in the EU [6]. The International Cancer Research Organization (IARC) stated in its 100C monograph that "silica or inhalation of quartz or cristobalite powder is carcinogenic to humans (Group 1 of carcinogens for humans)" [12,14].

The European Union Scientific Committee on Occupational Exposure Limits (SCOEL) has assessed the impact of crystalline silica (respiratory dust) on employee health, and has proposed a limit value of 0.1 mg / m^3 which would mean avoiding 99,000 cancer cases by 2069 with total health benefits valued at between € 34 billion and $ 89 billion [6]. The above proposal by SCOEL has led to the adoption of the European Union Directive 2017/2398 L 345/87 that aims at improving the prevention of occupational cancer cases that can be avoided [6].

Given the nature of the materials used in the construction industry, the powder may contain significant amounts of SiO_2 [1,15,20]. According to the International Labor Organization (ILO), silicification, an incurable disease, requires quantitative and qualitative control of respiratory crystalline silica and the development of appropriate control measures [21].

The importance of the current study is based on the fact that we need to take under consideration the high occupational exposure to airborne powders of people working at underground and outdoor construction, drilling, concrete launching and machinery movement together with the absence of relevant studies in Greece. The purpose of the study herein was to evaluate the exposure of workers to respiratory crystalline silica (SiO_2) and to examine the condition of workers' pulmonary function.

2. Materials and Methods

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The study involved 59 employees from one construction company mainly engaged in outdoor construction and 27 employees from a second construction company working exclusively at underground projects with their main activity being tunneling. A total of 86 employees participated all of which, suffered from active exposure to inhalable crystalline silicon dioxide. The construction workers who participated were categorized as artisans - builders, machine operators, builders - contractors, blasters, electricians, sorting and packaging workers.

The clinical/epidemiological history included both the medical and the professional one, in order to determine the relationship between exposure to a substance and the development of respiratory disease. The relevant information included the aggravating factors, the appearance and progression of the disease, the family and medical history of each exposed worker. Other medical allergic or respiratory disorders in childhood were, also reported in the medical history together with the smoking habits of each participant [22]. Certain characteristics (height, weight, age, years of work) of the exposed workers were, also, recorded.

To test for dust at the workplace (solid particles or mixtures suspended in the air), environmental measurements - samplings were performed to ensure compliance with national and European legislation on industrial hygiene. In the above measurements, the sampling time corresponded to at least four (4) hours and the analysis technique for determining the content of SiO_2 (mainly quartz and cristobalite) was carried out by various methods [22].

In the present study we followed the method of Fourier transform infrared spectroscopy (FTIR) for the nine (9) sampling filters in underground projects and for the eight (8) outdoor activities in order to calculate the individual exposure of respiratory SiO_2 in workers. Sampling took place during the period 2015-2017.

Individual sampling was performed with a SKC (USA) 224-PCTX Respiratory Dust Sampling Pump. The device was intended for the detection and measurement of particles (inert dust, toxic dust, etc.) in the work environment. The above device is a pump with a flow rate of 750-4000 ml / min with a built-in battery.

Samples were collected on a filter which was weighed before and after sampling and analyzed for the detection of crystalline silica. For the current samplings, a Dorr Oliver type head with a flow of 2 l / min was used to collect samples of 960 liters of air each, on a 37mm cellulose ester filter. Flow was checked before and after sampling.

Pulmonary function tests (PFTs) in our study were performed at the 1st Academic Department of Pneumonology of the General Hospital of Thoracic Diseases of Athens "Sotiria" using a spirometer (Cosmed, Quark PFT Pulmonary Function Testing and SensorMedics ™ Erich Jaeger).

Pulmonary functional test results were categorized as within normal limits, mild obstructive syndrome, mild decrease in diffusion capacity, small airway dysfunction, moderate restrictive syndrome, and upper thoracic airway dysfunction.

PFTs were performed using a commercially available system (Master Screen, Erich Jaeger GmbH, Wuerzburg, Germany). Forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), FEV_1/FVC ratio, forced expiratory flow in the middle 50% of FVC (FEF_{25-75}), Total Pulmonary Capacity (TLC) - Total Lung Capacity, Peripheral Capacity (DLco), and the Special Rate Di [Kco (DLco)] were recorded. Post-bronchodilator values were obtained 20 minutes after the administration of 400 mg salbutamol via a spacer. Diffusing capacity for carbon monoxide (DL_{CO}) and diffusing capacity for carbon monoxide adjusted for alveolar volume (DL_{CO}/V_A) were assessed by means of the single breath method with the patient being in the sitting position [23] Lung function measurements were expressed as percentages of predicted values [24]. The results were interpreted in accordance with the guidelines of the American Thoracic Society [25–27].

The chest x-rays of the participants were performed at the Department of Imaging and Interventional Radiology of the above-mentioned hospital; the Siemens X-RAY Diagnostics Axiom Vertix Solitaire M. radiograph was used.

To perform the chest high resolution computed tomography (HRCT), the INGENUITY CORE 64 system (Philips) was used.

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The radiographs were evaluated according to the system developed by the International Labor Office Classification System in 1980 [28,29].

Written consent was obtained from each employee who participated in the study. This research has been approved by the bioethics and ethics committee of the National and Kapodistrian University of Athens under the decision 6323 received on the 06th of March of 2013.

3. Results

All workers belonged to the same socioeconomic class, with an average age of 41.04 years (standard deviation of 9.68) and an average of 15.69 years of work (SD 10.30); most were former and current smokers and did not use prescription drugs. In more detail, underground construction workers had an average age of 41.26 years (SD 9.67) and an average of 18.70 (SD 11.32) working years. Outdoor construction workers had an average age of 40.93 years (SD 9.76) and an average of 14.31 (SD 9.59) working years.

3.1. Pulmonary function tests

The results of the PFTs performed are shown in Table 1.

Table 1. Pulmonary function test results

Test	Results	Frequency	%
	Not normal	3	3,7
RX % PRED FVC (Liters)	Normal	79	96,3
	Total	82	100
	Not normal	4	4,9
RX % PRED FEV 1 (Liters)	Normal	78	95,1
	Total	82	100
	Not normal	6	7,4
RX % PRED FEV 1 (Liters)	Normal	75	92,6
	Total	81	100
	Not normal	9	11,0
RX % PRED FEV 1 (Liters)	Normal	73	89,0
	Total	82	100
	Not normal	8	9,6
RX % PRED FEV 1 (Liters)	Normal	75	90,4
	Total	83	100
	Not normal	9	10,7
RX % PRED FEV 1 (Liters)	Normal	75	89,3
	Total	84	100
	Not normal	2	2,4
RX % PRED FEV 1 (Liters)	Normal	82	97,6
	Total	84	100

According to the analysis of the results, 51 employees (61.4%) were within normal limits, 22 (26.5%) were diagnosed with mild obstructive syndrome, four (4.7%) were diagnosed with mild impairment of diffusing capacity and two (2.4%) were diagnosed with moderate restrictive syndrome.

The project type (underground-outdoor) was significantly associated with categorization of pulmonary function test (P = 0.038). When comparing underground and outdoor construction workers (Graph 1) we revealed that underground workers were less likely to lie within normal limits compared to those working outdoors (53.8% vs 64.9% respectively).

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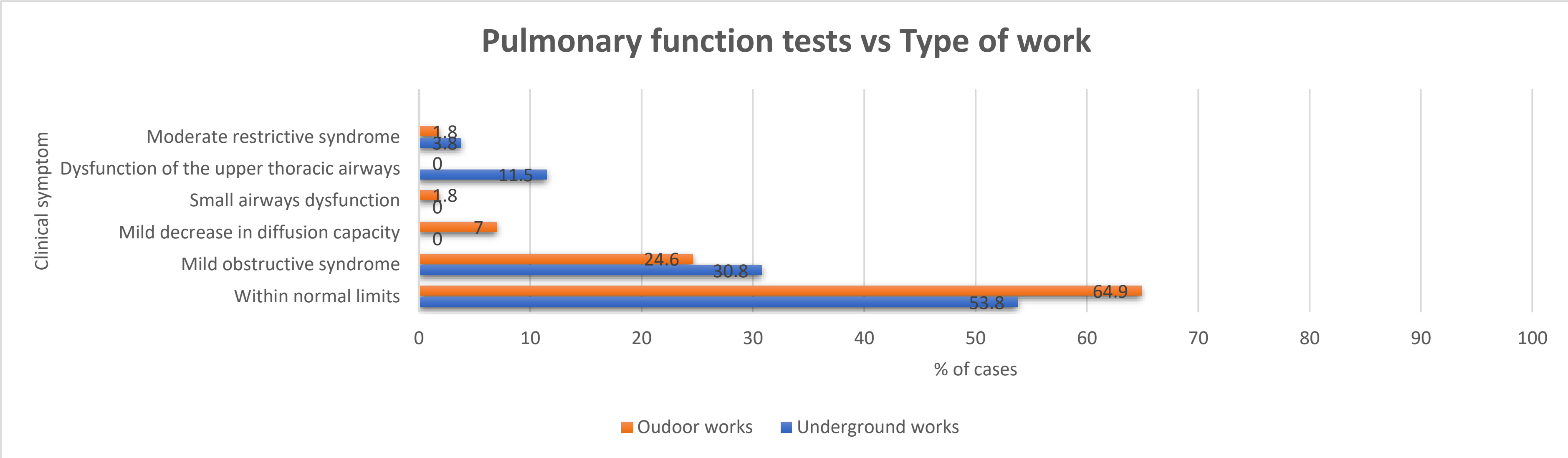

Figure 1. Comparison of results of functional respiratory testing by job type (underground and outdoor construction projects)

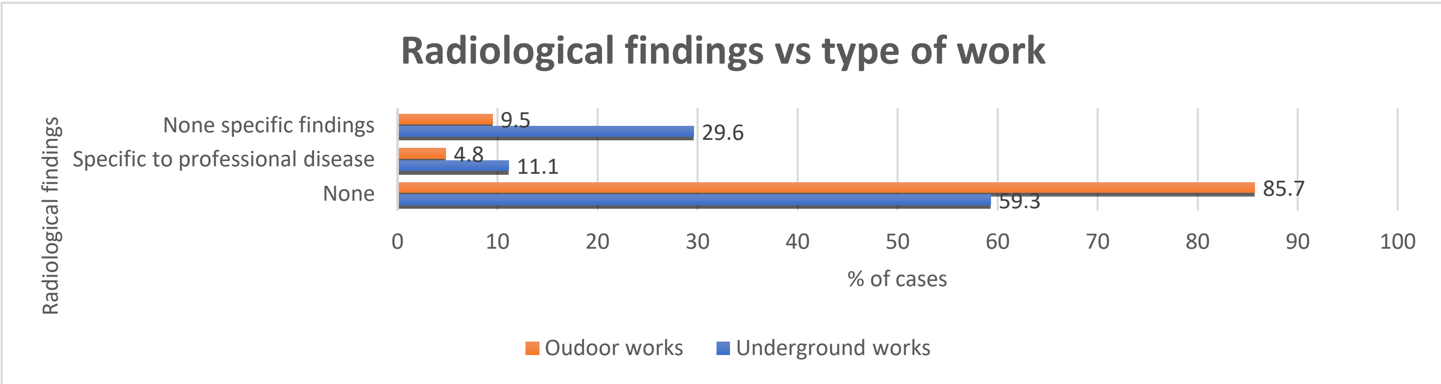

Figure 2. Categorization of radiology findings vs work type

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3.2. Radiology testing

Of the 86 workers, 69 participated in the radiological examination. The remaining 17 employees from the company engaged in outdoor construction projects, refused to participate in the radiological examination because they stated that they had performed this test at the same year as part of their collaboration with the company.

Of the 69 employees, in 52 (75.4%) no findings were recorded and five (7.2%) were diagnosed with specific occupational disease findings while 12 (17.4%) presented non-specific findings. One out of the five (5) subjects with abnormal findings in chest x-ray was diagnosed with lung cancer three months later.

Job type (underground-outdoor) was significantly associated with the categorization of radiological findings (P = 0.044). When comparing underground and outdoor construction workers (Figure 2) we revealed that underground workers were less likely to lack any findings (59.3% compared to 85.7% for those working outdoors).

Correspondingly, underground jobs were more likely to be linked both to specific and non-specific occupational radiological findings (Table 2).

3.3 Environmental SiO_2 measurements

High exposure to respiratory crystalline silica powder was observed among workers in underground excavation and tunneling. In particular, the concentration of SiO_2 in underground construction was 12 mg / m^3

Table 2. Radiological findings and type of job

Type of job	No findings	Specific to occupational disease	Non-specific
Underground	16 (59,30%)	3 (11,10%)	8 (29,6%)
Outdoor	36 (87,50%)	2 (4,80%)	4 (0,50%)

Corresponding radiological findings are shown in Figure 3. At one patient the chest x-ray revealed a suspicious right hilar enlargement, as an incidental finding. A subsequent CT scan of the chest confirmed the presence of a right hilar mass, consistent with lung cancer.

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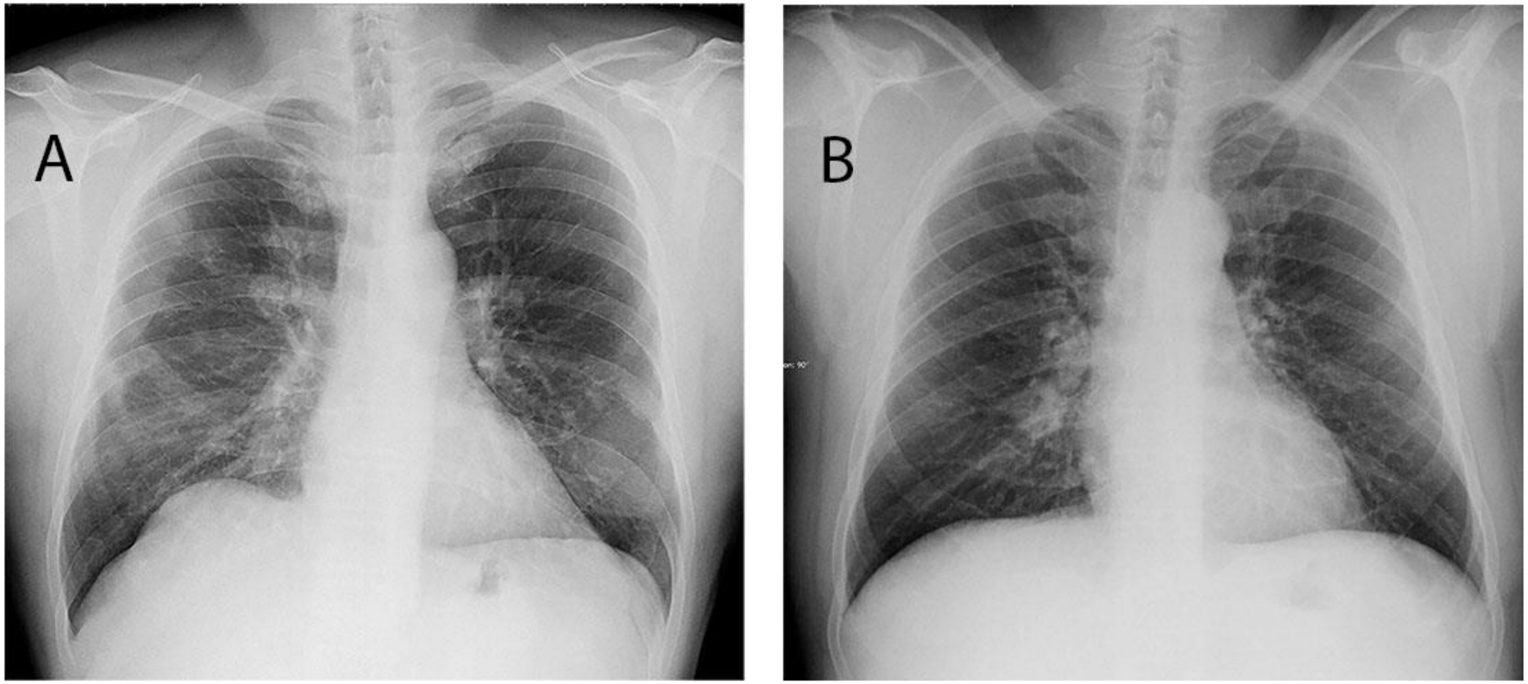

Figure 3. A: Chest x-ray showing right hilar enlargement. A subsequent CT scan confirmed a right hilar mass due to lung cancer. **B:** Chest X-ray showing bilateral calcified pleural plaques and linear opacities in the lower lung zones.

4. Discussion

Historically, silicosis is considered as a significant occupational disease and still is of interest [31]. Exposure of Greek employees, working to underground excavation and tunneling construction works on respiratory powder of SiO_2 crystalline silica was found to exceed the limits specified by the European and national legislation. Moreover, pulmonary function testing found that underground workers were less likely to lie within normal limits compared to those working outdoors.

During our study, environmental measurements were performed, samples were collected to detect breathable crystalline silica (SiO_2) in the workplace of outdoor and underground construction works, and medical tests of the pulmonary function tests of workers were carried out. Chest X-rays, as well as, High Definition Computed Tomography (HRCT) were also performed where deemed appropriate in order to obtain a better picture of the diagnosis.

High exposure to respiratory crystalline silica powder was observed among workers in underground excavation and tunneling. In particular, the concentration of SiO_2 in underground construction was 12 mg / m^3, in excess of the limit value of 0.1 mg / m^3 set by the European Union Directive 2017/2398 / L345 / 87. This limit value is also laid down in the National Mining and quarrying legislation [32]. The above finding is consistent with the study by Calvert et al. in which researchers conclude that overexposure to respiratory SiO_2 is 30 times more likely to cause death than low exposure workers [33].

Despite the existence of regulated thresholds at both European and national levels, exposure to high concentrations is still observed. In particular, it was observed that all underground workers were exposed to respiratory SiO_2 compared to those working outdoors where no SiO_2 was present.

The above concentration of SiO_2 in the dust generated in underground construction projects, which far exceeds the limit set by the legislative framework, makes it detrimental to the health of workers in this area [30]. The above findings are in agreement with the findings of the Tavakol et al. study [15]. A similar conclusion about exceeding the exposure limit on respiratory SiO_2 in underground excavation works is presented at the Mazurek and Attfield's research [18]. An important factor in the above threshold exceed is the production process carried out in underground excavation projects that involves the frequent use of sprayed concrete, also known as GUNITE.

Based on the results of the pulmonary function testing in the present study, underground workers were more likely to lie outside the normal limits compared to those working outdoors. In a study by Hochgatterer et al. (2013), occupational quartz exposure adversely affected lung function parameters [34].

The finding that five workers presented occupational disease-specific pathological findings can be considered serious especially since these workers had worked > 15 years in underground construction - excavation and tunneling projects. This is further supported by the establishment of lung cancer diagnosis in one subject three months after the inclusion in this study. According to the conclusions of the study of Kachuri et al. [19], prolonging the activity of exposed workers for more than 30 years, that is, long exposure to crystalline SiO_2, is likely to increase the risk of developing lung cancer [9,19].

It is worth noting that people working in underground construction projects were fewer in number due to the financial crisis in Greece from 2010 to date. Underground and outdoor projects have been reduced in numbers throughout the country.

5. Conclusions

People in the Greek construction industry are exposed to crystalline silica powder that exceeded the limit value as laid down in the European legislation. People working mainly in underground tunneling projects have a higher exposure to SiO_2 compared to the statutory limit. Workers at these activities with more than 15 years exposure to SiO_2 are more likely to develop silicosis in its chronic form [35]. As a result, further precautionary measures are required for workers in the construction sector to promote their health and safety. In particular, the following steps are suggested: a) a more frequent training in safe work practices [36,37], b) the use of appropriate respiratory protection devices in accordance with the requirements of European legislation [38], c) undertaking of workers to precautionary measures, d) undergoing of medical tests every year and e) periodic workplace sampling to perform respiratory crystalline silicon analyzes with the results being compulsory reported to the Competent Authority [30,39]. Finally, the establishment of a National Occupational Health and Safety System is needed to identify risk factors in the work environment in accordance with the National Occupational Health and Safety Strategy [40].

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