RESEARCH ARTICLE

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Assessment of Cancer Rate in Mine Workers Exposed to Crystalline Silica

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Abstract

Objective: Exposure to Respirable Crystalline silica is considered a significant occupational hazard that can greatly impact the health of workers in mining industries. Consequently, the objective of this study is to evaluate the potential risks associated with exposure to crystalline silica for workers employed in mine. **Methods:** In this descriptive-analytical study, evaluate the occupational exposure of 65 mine workers across five distinct occupational groups by NIOSH 7500 method. To assess the probability of mortality resulting from silicosis and lung cancer, utilized the Mannetje and Rice model. Moreover, the study also focused on evaluating the carcinogenic and non-carcinogenic risks associated with occupational exposure to silica by using the method recommended by the US EPA. **Results:** The results of the study indicate that the crusher section, which had a concentration of 0.53 mg/m3, showed the highest level of silica exposure, while the security section, with a concentration of 0.09 mg/m3, exhibited the lowest concentration of Respirable Crystalline silica exposure. The results showed that 85% of the samples exceeded the established occupational exposure limit. The risk of death from lung cancer, as indicated by Rice et al.'s linear model, was estimated to be between 15-139 deaths per 1000 worker exposed to Respirable Crystalline silica. However, according to the Mannetje model, worker with a cumulative exposure range of 4.33-2.84 have a 26.3% risk of developing lung cancer. This cause to approximately 6.3 deaths/1000 P. The carcinogenic risk of 92.1% and the non-carcinogenic risk of 65.5% of the workers were at an unacceptable level. **Conclusion:** Considering the elevated levels of average exposure within work groups, as well as the increased risk of mortality associated with silicosis and lung cancer, it is imperative to implement comprehensive management and engineering control for the mine workers.

Keywords: Silica exposure- risk assessment- lung cancer- silicosis- mine workers

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Introduction

Silica, as the most abundant mineral found in the Earth's crust, poses a widespread occupational hazard across various industries. Present in nature as quartz, cristobalite, and tridymite, respirable crystalline silica(RCS) poses a considerable risk to workers in various industry such as tiles and ceramics [1], glass industries [2], construction activities [3], and casting [4]. workers in the mining industry are exposed to dangerous concentrations of RCS, which can lead to a range of respiratory diseases. Prolonged exposure to RCS can result in chronic lung inflammation and ultimately progress to lung fibrosis. The precise mechanism underlying this disease remains undetermined, with numerous theories proposed; however, the hypothesis implicating damage to alveolar macrophages is widely accepted [5] In October 1996, the IARC designated silica as a potential human carcinogen. However, the evidence regarding its carcinogenicity was initially uncertain [6]. Nevertheless, in 2009, another group within the IARC examined exposure-response and cohort studies, ultimately concluding that the inhalation of silica in the form of quartz and cristobalite in occupational environments poses a carcinogenic risk to humans. Consequently, silica was classified as a Group 1 (A1) carcinogen [7]. Inhalable and respirable forms of silica have been found to have adverse health effects. Silicosis, a debilitating lung disease, is widely recognized as one of the most significant health issues associated with silica exposure. National Institute for Occupational Safety and Health (NIOSH) estimates that over 1.7 million workers in the united States, more than 2 million in Europe [8], and over 23 million in China have been exposed to silica [9]. Rice and colleagues conducted a risk assessment

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for lung cancer among workers who were exposed to crystalline silica. They also estimated the anticipated lifelong risk of mortality from lung cancer based on a continuous work history of 45 years with 10-year intervals [10]. In recent years, the discussion of risk assessment has become one of the most important topics in the control of occupational diseases, and the risk of developing silicosis was conducted based on the model provided by Mannetje, in which the relative risk of mortality for 5-year cumulative exposure in mg/m^3, it was 13.7% per thousand people [11]. While in the cohort study conducted on 3010 Chinese workers, the observed risk was found to be 33.7%. Given that crystalline silica is a highly hazardous contaminant encountered by workers in mining operations, it becomes crucial to thoroughly investigate and assess the associated risks of exposure to this substance [12]. In order to protect mine workers from the health risks of exposure to crystalline silica, engineering methods such as local ventilation and air purification systems should be used to control exposure. Therefore, the primary objective of this research is to evaluate the concentration of crystalline silica exposure and determine the mortality risks, specifically related to silicosis and lung cancer, among workers in an eastern mine. Additionally, this study aims to assess the carcinogenic risks associated with occupational exposure to silica in this particular mining site.

Materials and Methods

In this study, the NIOSH7500 method was employed to evaluate the level of exposure to RCS. This method utilizes the x-ray scattering technique, regarded as the most precise approach for quantifying RCS in air samples. A study was conducted to sample the breathing areas in Four different job categories: the stone crusher, conveyor belt, production, storage, and security workers. This was achieved using the SKC Personal Sampler Pump (UK), along with a nylon cyclone fitted with a PVC filter 25mm in diameter and with a pore size of 0.8 microns. A total of 65 samples were collected for analysis, with a sampling rate of 1.7 liters per minute as part of the sampling process, filters were placed in a desiccator for 24 hours prior to and after sampling to eliminate any moisture accumulation. The filters were then weighed using a Laboratory scale with a precision of 0.00001 grams. In order to analyze the samples using the X-ray diffraction method, a calibration curve was constructed within the concentration range of 20-1000 micrograms. Following this, standard solutions were filtered through a silver membrane filter to analyze the original samples. The PVC filter was treated with tetrahydrofuran after which the diffraction intensity of the original samples was compared with the standards [13]. In this study, in order to evaluate the risk of death due to silicosis, the model provided by Mannetje et al. was used for a 10-year period. In this model, the cumulative exposure of silica in the range between 0 and 0.99 to more than 18.10 mg per cubic meter per year is considered. In fact, the two main parameters in this model are exposure years and silica concentration in mg/m^3 [11].

In this study the computation of mortality risks associated with silicosis and lung cancer by employing the linear model established by Rice et al. The calculation utilizes the geometric mean of silica exposure among workers, as determined by the following formula, where "GM" represents the geometric mean of workers' silica exposure [10].

$$A=0.77+373.69\times GM \qquad \text{Equation 1}$$

Quantitative risk assessment

A quantitative risk assessment was conducted using the methodology established by the USEPA . This approach involves the calculation of cancer risks associated with a specific chemical compound using Equation 2, while non-cancer related health risks are determined using Equations3 and 4

$$LCR = \frac{\mathrm{C \times BR \times DS \times EF \times ED}}{\mathrm{BW \times AT}} \times SF \qquad \text{Equation 2}$$

$$EC = \frac{C \times DS \times EF \times ED}{\mathrm{AT}} \qquad \text{Equation 3}$$

$$\mathrm{HQ}=\frac{EC}{RfC} \qquad \text{Equation 4}$$

where LCR = incremental lifetime cancer risk, HQ = hazard quotient, C = exposure concentration in air (mg/m^3), BR = breathing rate (m^3/hr), DS = daily shift (hr/day), EF = exposure frequency (day/ year), ED = exposure duration (years), BW = bodyweight (kg), AT = averaging time for cancer effects (equals to the life expectancy in days), SF = cancer slope factors (mg/kg.day), and REL = chronic reference exposure level (mg/m^3).

The breathing rate for men is in light work: 0.8(m^3/hr), moderate work: 0.5(m^3/hr) and heavy work:0.6 (m^3/hr). The cancer slope factor (SF) refers to a 95% confidence level that determines the likelihood of developing cancer over a lifetime as a result of exposure to a hazardous compound.

Statistical analysis

This statistical measure is provided by the International Agency for Research on Cancer (IARC). However, it is important to note that there is currently no specific SF value available for silica within the Integrated Risk Information System (IRIS), which is used for assessing health risks. Various studies involving animals and humans have been conducted to estimate the SF values for silica. These studies have yielded a range of estimated values, falling between 6.8×10^{-7} and 1.85×10^{-5}. Table 1 provides the requisite information necessary for evaluating the risks associated with both carcinogenesis (cancer development) and non-carcinogenesis [14].

According to the EPA standards, the acceptable risk level for environmental exposure to chemical compounds is defined as one per 1,000,000 and 1 in 1000 in occupational contacts [17]. According to studies, LCR

Table 1. Risk Factor Variables Risks associated with Ricecarcinogenesis and Non-Carcinogenesis

Input parameter	Section	Distribution values	Basis
Chemical concentration (C)	mg/m^3	-	Data calculated
Breathing rate (BR)	m^3/ hr	heavy activities (miner workers) = 0.6 Light bactivities security=0.8	U.S. EPA (2011) [15]
Daily shift, (DS)	hours/day	8	(Working hours)
Exposure frequency, (EF)	days/year	300	Questionnaire
Exposure duration (ED)	years	-	Questionnaire
Averaging time for cancer effects (equals to the life expectancy in years),(AT)	days	For carcigonecty 70 years × 365 day/year = 25550 For non carcigonecty 70years×365 day/years×24 hr=613200	U.S. EPA (2011) [15]
Bodyweight, (BW)	kg	-	Data calculated
Cancer slope factors, SF	(mg /kg .day)	1.85×10^{-5}, 6.8×10^{-7}	Goldsmith et al. (1995) [14]
Chronic reference exposure level, RfC	mg/m^3	0.025	ACGIH (2010) [16]

OAQPS, Office of Air Quality Planning and Standards

more than 10^{-4} is classified as Definite Risk, 10^{-4} to 10^{-5} is probable risk and between 10^{-5} and 10^{-6} is Possible Risk [18-20]

In addition, a value of HQ>1 indicates the presence of concerns regarding non-carcinogenic effects, whereas HQ≤1 suggests an acceptable level of risk. Statistical analyses were conducted using SPSS version 21 software. Descriptive statistical tests were employed to calculate the mean and standard deviation of both arithmetic and geometric exposure across various sections. Furthermore, the normality of the data was assessed using the Kolmogorov-Smirnov test, while the t-test was utilized to compare the exposure levels of individuals with the national limit. The carcinogenic and non-carcinogenic rates in different job groups were determined through the use of a one-way ANOVA test, and the risk level in distinct job groups was assessed using the chi-square test.

Results

The east iron ore mines are one of the largest mines in Iran, with more than 10,000 workers. This study was conducted in one of the mines with 500 workers, a total of 65 mine workers participated, with an average age of 34.76 years, work experience 8.89 years, and a body mass index of 25.57. These participants were divided into six distinct job groups, namely stone crusher, conveyor, production section, storage section, transportation, and security. Table 2 displays the demographic characteristics of workers specific to each job section.

The results of the assessment of workers' exposure to RCS in various areas are presented in Table 3, including measurements of the geometric and arithmetic means. The findings indicate that the crusher section exhibited the highest silica exposure (0.53 ± 0.08), while the security area had the lowest average exposure (0.09 ± 0.07). The average silica exposure varied significantly across different sections (p=0.0001). It is important to note that the permissible occupational exposure limit for crystalline silica, as stated by the standard set by the Occupational Health Committee of Iran, is 0.025 mg/m^3 [21]. Surprisingly, the study revealed that 85% of the samples exceeded this limit, further emphasizing the concerning nature of the findings.

Furthermore, the impact of silicosis mortality risk on mine workers resulting from their exposure to RCS based on Mannetje model, is presented in Table 4. The table reveals that a considerable 27.6% of worker fall within the risk range of 2.84-4.33 cumulative exposure, equating to a mortality rate of 6.3 deaths per thousand people. Additionally, approximately 20% of the samples display a relative risk of 2 deaths per 1000 people exposed. Notably, none of the samples were subjected to a cumulative exposure range of 28.1-15.89, which demonstrates a substantial relative risk of 60.5 deaths per thousand people (Table 4).

The findings pertaining to the estimation of mortality risk associated with lung cancer among mine factory workers exposed to silica dust are showcased in Table 5. This study utilized the linear model developed by Rice et al. to assess the risk of lung cancer-related fatalities. The results indicate that the risk of death due to lung cancer ranged between 15 and 139 per 1000 individuals exposed to silica [10]

The risk of silica carcinogenesis among mine workers was assessed by considering the cancer slope factor using two distinct values: 1.85×10^{-5} and 6.8×10^{-7}. The findings revealed that an alarming 92.1% of mine workers had an unacceptable level of carcinogenic risk (above 10^{-6}). Furthermore, there were no significant differences in the carcinogenic risk observed across different occupational groups. Among these groups, the highest percentage of workers with a carcinogenic risk was identified in the production section occupational group, accounting for 22.2% (Table 6). In terms of non-carcinogenic risk assessment, the evaluation of silica exposure demonstrated that 65.6% of individuals were exposed to an unacceptable level of risk. Among the various occupational groups,

Table 2. Demographic Characteristics of Mine Workers Exposed to RCS in Different Occupational Groups

		N	Mean	Std. Deviation	Minimum	Maximum	p-value
Age	Stone crusher	9	29.33	6.18	22	39	
	Conveyor	10	34.1	6.95	24	45	
	Production	15	34.6	7.66	24	48	
	Storage	12	33.75	6.91	24	43	0.08
	Transport	10	37.7	10.19	26	56	
	Security	8	39.87	5.24	33	48	
	Total	64	34.76	7.76	22	56	
Job	Stone crusher	9	5.77	3.59	1	11	
	Conveyor	10	9	4.98	3	17	
	Production	15	9.06	5.09	2	17	0.34
	Storage	12	8.5	5.26	2	16	
	Transport	10	10.3	5.63	4	18	
	Security	9	10.75	3.77	6	17	
	Total	65	8.89	4.9	1	18	
Body Map Index	Stone crusher	9	25.59	1.31	23.67	28.23	
	Conveyor	10	26.24	1.406	23.67	28.23	
	Production	15	25.71	1.3	23.15	27.55	0.002
	Storage	12	25.76	1.64	23.15	29.3	
	Transport	10	26.12	1.416	23.67	28.23	
	Security	9	23.45	1.275	21.68	25.35	
	Total	65	25.57	1.58	21.68	29.3	

Table 3. The Results of Measuring Exposure to Crystalline Silica (mg/m^3) in Different Parts of the Mine

Groups	N	Arithmetic mean	SD	Geometric mean
Stone crusher	9	0.53	0.08	0.37
Conveyor	10	0.33	0.11	0.21
Production	15	0.3	0.12	0.19
Storage	12	0.47	0.1	0.27
Transport	10	0.21	0.07	0.14
Security	9	0.09	0.02	0.04
Total	65	0.31	0.15	0.22

workers in the storage room exhibited the highest percentage of non-carcinogenic risk assessment at 17.2% (Table 7).

Discussion

The objective of this study is to evaluate the silica exposure among mine workers and evaluate the potential

Table 4. Mortality Risk Related to Silicosis in Worker Exposure based on Cumulative Exposure (mg/m^3-year) to Crystalline Silica (based on Mannetje model)

Cumulative exposure	Assessing the Relative Risk of Silicosis-Related Mortality per 1,000 Expose	Number of exposed workers (percentage)
0 – 0.99	2	13 (%20)
0.99 -1.97	2.4	10 (%15.3)
1.97 -2.87	7.2	9 (%13.8)
2.87 -4.33	6.3	18 (% 27.6)
4.33 -7.12	11.7	3 (% 4.6)
7.12 -9.58	7.8	5 (%7.6)
9.58 -13.21	24	5 (% 7.6)
13.21 -15.89	38.1	2 (%3)
15.89 -28.1	60.5	0

Table 5. Increased Mortality Risk due to Lung Cancer in Workers based on the Linear Regression Model of Rice

Groups	N	Arithmetic mean	Estimating Lung Cancer Mortality Risk Utilizing Rice et al.'s Model
Stone crusher	9	0.37	139
Conveyor	10	0.21	79
Production	15	0.19	71
Storage	12	0.27	101
Transport	10	0.14	53
Security	9	0.04	15
Total	65	0.19	71

Table 6. Evaluation of Carcinogenic Risk of Exposure to Silica in Occupational Group

		Mean	Minimum	Maximum	p-value
	Stone crusher	4.75×10^{-5}	5.28×10^{-6}	1.23×10^{-4}	
	Conveyor	4.40×10^{-5}	1.06×10^{-6}	1.10×10^{-4}	
	Production	3.70×10^{-5}	5.04×10^{-6}	8.84×10^{-5}	
	Storage	5.62×10^{-5}	5.28×10^{-6}	1.58×10^{-4}	
Slop factor= 1.85×10^{-5}	Transport	2.28×10^{-5}	1×10^{-6}	6.46×10^{-5}	0.14
	Security	1.83×10^{-5}	8.34×10^{-6}	3.26×10^{-4}	
	Total	3.95×10^{-5}	5×10^{-6}	1.58×10^{-4}	
	Stone crusher	1.84×10^{-6}	1.94×10^{-7}	4.55×10^{-6}	
	Conveyor	1.16×10^{-6}	3.67×10^{-7}	4.06×10^{-6}	
Slop factor=.6.8×10^{-7}	Production	1.37×10^{-6}	1.83×10^{-7}	3.24×10^{-6}	
	Storage	2.06×10^{-6}	1.94×10^{-7}	5.82×10^{-6}	0.11
	Transport	1.04×10^{-6}	3.67×10^{-7}	2.37×10^{-6}	
	Security	6.73×10^{-7}	3×10^{-7}	1.19×10^{-6}	
	Total	1.45×10^{-6}	1.83×10^{-7}	5.82×10^{-6}	

Table 7. Non-Carcinogenic Risk Assessment of Exposure to Silica in Occupational Groups

HQ	Mean	Minimum	Maximum
Stone crusher	2.46	1.5	3.8
Conveyor	1.65	0.85	2.49
Production	1.36	0.7	2.49
Storage	2.21	0.89	3.57
Transport	0.99	0.56	1.78
Security	0.46	0.14	1.03
Total	1.55	0.14	3.8

risks associated with silicosis and lung cancer mortality. The findings of this study provide an estimation of the mortality rate among workers who have been exposed to silica. It is worth noting that the average silica exposure in this study was above the standard exposure level set by (OSHA) at 0.05 mg/m^3, as well as Iran's permissible level of 0.025 mg/m^3. Additionally, Azari et al. [24] conducted a similar study in construction workers in Tehran, and their research also revealed exposure levels surpassing permissible limits, consistent with the findings of this study [10]. In a study conducted by Nourmohammadi et al., their objective was to evaluate the concentration of exposure to crystalline silica during building demolitions of old houses in Tehran. The findings revealed that in 80% of the samples exceeded the occupational exposure limit [22]. These results align with previous studies and demonstrate that in mining and construction settings, workers face excessive exposure to crystalline silica that surpasses the permissible limit. Consequently, individuals afflicted with occupationally-related illnesses can impose a substantial financial burden on the healthcare system of the country. The research conducted by Rahimi Moghadam et al. [23] revealed that the mean silica exposure among workers in the concrete industry was determined to be 0.025 mg/m^3. Furthermore, the risk assessment conducted on workers exposed to crystalline silica in the eastern region of Tehran demonstrated that occupational exposure levels in construction workshops exceeded the standard limit of 0.05 mg/m^3. The reported geometric mean exposure level was found to be 0.193 mg/m^3 [24]. Numerous research studies have been conducted to establish a correlation between silica exposure and mortality from silicosis and lung cancer. These studies consistently reveal a significant association between the exposure to crystalline silica and the risk of death from both silicosis and lung cancer. In this study utilized the Mannetje model to estimate the risk of death from silicosis and the Rice model to assess the risk of death from lung cancer. According to the Mannetje model, approximately 20% of worker exposed to silica fall within the range of 0 to 0.99, indicating a mortality rate of one person per thousand [11]. In the study conducted by Rahimi Moghadam et al., the researchers estimated the mortality risk to be 94.7 per thousand worker among concrete workers [25]. Additionally, their findings demonstrated a noteworthy decline in pulmonary indices among workers who were exposed to silica for a duration of four years. Chen and colleagues conducted a prospective study, investigating mortality rates among seven thousand individuals working in four small mines in China who were exposed to silica and mixed particles. This study revealed that lung cancer, as a consequence of silica exposure, ranked as the third leading cause of death among the workers, with a prevalence rate of 7% across all samples [12]. In the year 2000, Finkelstein conducted a comprehensive study examining the threshold for exposure and associated cancer risks associated with silica particles. His findings revealed that adherence to the OSHA recommended limit of 0.05 mg/m^3 resulted in a significant 30% probability of developing lung cancer. Conversely, following the guidelines proposed by the NIOSH, which recommend an occupational dose of 0.01 mg/m^3, the risk of cancer was effectively reduced to below 5% [26].Considering that the permissible limit for lung cancer mortality in Iran aligns with the standards set by the NIOSH organization, ranging from 0.9-0.9 mg/m^3-year, it can be inferred that the protection provided to workers may be somewhat restricted. However, emphasizing the significance of stringent control measures and continuous monitoring can effectively narrow the gap in terms of adverse health effects and bring it in line with global benchmarks. In a comprehensive cohort study, researchers assessed the potential risk of cancer-related mortality associated with silica exposure among a substantial sample of 34,000 workers over a span of 44 years. Within this time frame, a total of 542 deaths attributed to lung cancer were reported [12] The findings of this study, alongside similar research conducted by Steenland et al., revealed comparable rates of lung cancer and silicosis risk, as well as the proportion of deaths resulting from these conditions. These compelling outcomes underscore the paramount significance of effectively controlling exposure to silica and implementing systematic monitoring practices as preventive measures against cancer development [27]. The average risk of silica-induced carcinogenesis among mine workers is estimated to be 3.95×10^{-5} when considering a cancer slope factor of 1.85×10^{-5}, and 1.45×10^{-6} when accounting for a cancer slope factor of $6.8\text{x}10^{-7}$. Based on the calculated cancer slope factor of 1.85, an alarming 92.1% of individuals are found to possess an unacceptable risk of developing cancer due to silica exposure. However, when the cancer slope factor is adjusted to 6.8, the risk of carcinogenesis in the entire population falls within an acceptable range.

In a study conducted by Borjui et al. in a Porcelain manufacturing industry, the evaluation of both carcinogenic and non-carcinogenic risks associated with exposure to crystalline silica was investigated. The average occupational exposure to crystalline silica was found to be 0.1 ± 0.57 mg/m^3, with all occupational groups demonstrating a carcinogenic risk below 10^{-6}, which is considered acceptable [28]. Additionally, Mohammadi Kaji conducted a study examining the levels of cancerous and non-cancerous risks among workers exposed to crystalline silica dust in the welding electrode production process [29]. The study investigated two cancer slope factors of 1.85 and 6.8. The results revealed that the risk levels of all workers in various job groups were lower than the estimated range of 10^{-6}, indicating an acceptable level of risk. the average risk assessment value was found to be 1.55, indicating that a considerable proportion of the population, specifically 65.5%, was exposed to silica at levels deemed unacceptable, the research focused on the chinaware manufacturing industry, specifically investigating the stone crusher, slurry, filter press, and dryer occupational groups. In these groups, the non-carcinogenic risk exceeded the threshold value of one, placing them within the unacceptable range. By analyzing different areas within the industry, it was revealed that the production section occupation had the highest percentage of carcinogenic risk (22.2%), followed by the storage, transportation, and conveyor section occupation (15.9%). Conversely, the security occupation had the lowest risk for both carcinogenic and non-carcinogenic effects. This suggests that workers in the security occupation were exposed to lower levels of silica compared to other occupational groups, resulting in reduced risks of carcinogenesis and non-carcinogenesis.

In conclusion, assessing the risk of mortality resulting from silica exposure, as well as the incidence of silica-related cancer, underscores the significance of this substance and the need to address its potential hazards. Our study, along with other research studies, consistently highlights the substantial risk associated with silica exposure. Consequently, there is a pressing requirement for reevaluating assessments, laws, and engineering as well as management control methods pertaining to this material. Additionally, the existing exposure limit must be reexamined to ensure its efficacy. The NIOSH has established an exposure limit for silica in the workplace. This limit is set at 0.05 mg/m^3, calculated as the average concentration over an eight-hour workday. It is imperative to acknowledge that exposure to silica poses a grave health concern, demanding attention from both workers and employers, as well as regulatory agencies. By implementing preventive measures, such as the promotion of safe workplace practices, utilization of protective equipment, and limitation of exposure, the risk of health complications associated with silica exposure can be significantly mitigated.

Author Contribution Statement

All authors contributed equally in this study.

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References

1. Nourmohammadi M, Yari S, Rahimimoghadam S. Effect of Occupational Exposure to Crystalline Silica on Pulmonary Indices in Tile and Ceramic Workers. Asian Pacific J Environ Cancer. 2022;5(1):45–8. https://doi.org/10.31557/apjec.2022.5.1.45-48

2. Mehta A, Ashish DK. Silica fume and waste glass in cement concrete production: A review. J Build Eng. 2020;29:100888. https://doi.org/10.1016/j.jobe.2019.100888
3. Kakooei H, Nourmohammadi M, Mohammadian Y, Zarei E, Zokaei M. Assessment of occupational exposure to crystalline silica during demolition of buildings in Tehran. Iran Occup Heal. 2014;11(2):63–9.
4. Tong R, Cheng M, Ma X, Yang Y, Liu Y, Li J. Quantitative health risk assessment of inhalation exposure to automobile foundry dust. Environ Geochem Health. 2019;41(5):1–15. https://doi.org/10.1007/s10653-019-00277-8
5. Tan S, Chen S. The mechanism and effect of autophagy, apoptosis, and pyroptosis on the progression of silicosis. Int J Mol Sci. 2021;22(15):8110. https://doi.org/10.3390/ijms22158110
6. IARC. International Agency for Research on Cancer IARC Monographs on the Evaluation of Carcinogenic Silica , Some Silicates , Coal Dust. Int Agency Res O N Cancer IARC Monogr Eval Carcinog Silica , Some Silic , Coal Dust. 1997.
7. Administration OS and H. Occupational Exposure to Respirable Crystalline Silica. Final rule. Fed Regist. 2016;81(58):16285-890.
8. Maciejewska A. Occupational exposure assessment to crystalline silica dust: Approach in Poland and worldwide. Int J Occup Med Environ Health. 2008;21(1):1. https://doi.org/10.2478/v10001-008-0010-3
9. Chen W, Liu Y, Wang H, Hnizdo E, Sun Y, Su L, et al. Long-term exposure to silica dust and risk of total and cause-specific mortality in Chinese workers: A cohort study. PLoS Med. 2012;9(4):e1001206. https://doi.org/10.1371/journal.pmed.1001206
10. Park R, Rice F, Stayner L, Smith R, Gilbert S, Checkoway H. Exposure to crystalline silica, silicosis, and lung disease other than cancer in diatomaceous earth industry workers: A quantitative risk assessment. Occup Environ Med. 2002;59(1):36–43. https://doi.org/10.1136/oem.59.1.36
11. 'T Mannetje A, Steenland K, Attfield M, Boffetta P, Checkoway H, DeKlerk N, et al. Exposure-response analysis and risk assessment for silica and silicosis mortality in a pooled analysis of six cohorts. Occup Environ Med. 2002;59(11):723–8. https://doi.org/10.1136/oem.59.11.723
12. Chen W, Liu Y, Wang H, Hnizdo E, Sun Y, Su L, et al. Long-term exposure to silica dust and risk of total and cause-specific mortality in Chinese workers: a cohort study. PLoS Med. 2012;9(4):e1001206. https://doi.org/10.1371/journal.pmed.1001206
13. Cauda E, Chubb L, Reed R, Stepp R. Evaluating the use of a field-based silica monitoring approach with dust from copper mines. J Occup Environ Hyg. 2018;15(10):732–42. https://doi.org/10.1080/15459624.2018.1495333
14. Goldsmith DF, Ruble RP, Klein CO. Comparative cancer potency for silica from extrapolations of human and animal findings. Scand J Work Environ Health. 1995;21 Suppl 2:104–7.
15. EPA. US. Exposure Factors Handbook 2011 Edition (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.
16. Hygienists. AC of GI. ACGIH® releases 2016 editions of TLVs® AND BEIs® book and guide to occupational exposure values. ACGIH, 2018.
17. Heibati B, Pollitt KJG, Karimi A, Charati JY, Ducatman A, Shokrzadeh M, et al. BTEX exposure assessment and quantitative risk assessment among petroleum product distributors. Ecotoxicol Environ Saf. 2017;144:445–9. https://doi.org/10.1016/j.ecoenv.2017.06.055
18. (OEHHA). O of EHHA. Technical Support Document for Cancer Potency Factors. 2011. vol. 65 1–21. Available from: http://oehha.ca.gov/prop65/law/pdf_zip/100711_4MEIfindings.pdf
19. Mohammadyan M, Moosazadeh M, Borji A, Khanjani N, Rahimi Moghadam S, Behjati Moghadam AM. Health risk assessment of occupational exposure to styrene in Neyshabur electronic industries. Environ Sci Pollut Res. 2019;26(12):11920–7. https://doi.org/10.1007/s11356-019-04582-8
20. Mohammadyan M, Moosazadeh M, Khanjani N, Rahimi Moghadam S. Quantitative and semi-quantitative risk assessment of occupational exposure to lead among electrical solderers in Neyshabur, Iran. Environ Sci Pollut Res. 2019;26(30):31207–14. https://doi.org/10.1007/s11356-019-06220-9
21. Golbabaei F, Gholami A, Teimori-Boghsani G, Yaseri M, Kianmehr M. Evaluation of occupational exposure to silica dust in mining workers in eastern Iran. Open Environ Res J. 2019;12(1).
22. Normohammadi M, Kakooei H, Omidi L, Yari S, Alimi R. Risk assessment of exposure to silica dust in building demolition sites. Saf Health Work. 2016;7(3):251–5. https://doi.org/10.1016/j.shaw.2015.12.006
23. Moghadam SR, Khanjani N, Mohamadyan M, Emkani M, Yari S, Tizabi MNL, et al. Changes in spirometry indices and lung cancer mortality risk estimation in concrete workers exposed io crystalline silica. Asian Pac J Cancer Prev. 2020;21(9):2811. https://doi.org/10.31557/APJCP.2020.21.9.2811
24. Azari MR, Rokni M, Salehpour S, Mehrabi Y, Jafari MJ, Moaddeli AN, et al. Risk assessment of workers exposed to crystalline silica aerosols in the east zone of Tehran. Tanaffos. 2009;8(3):43–50.
25. Moghadam SR, Abedi S, Afshari M, Abedini E, Moosazadeh M. Decline in lung function among cement production workers: a meta-analysis. Rev Environ Health. 2017;32(4):333–41. https://doi.org/10.1515/reveh-2017-0017
26. Finkelstein MM. Letter concerning: Occupational exposures to cosmetic talc and risk of mesothelioma: an updated pooled cohort and statistical power analysis with consideration of latency period by Gary M. Marsh et al.(Inhal Toxicol. 2019 Aug 5: 1–11. doi: 10.1080/08958378.2019. 1645768). Inhalation Toxicology. 2019;31(13-14):429-31. https://doi.org/10.1080/08958378.2019.1705940
27. Steenland K, Mannetje A, Boffetta P, Stayner L, Attfield M, Chen J, et al. Pooled exposure–response analyses and risk assessment for lung cancer in 10 cohorts of silica-exposed workers: an IARC multicentre study. Cancer Causes Control. 2001;12(9):773–84. https://doi.org/10.1023/a:1012214102061
28. Shojaee BS, Azimzadeh HR, Mosleh AA, Kuchakzadeh MR. Occupational monitoring and health risks assessment of respiratory exposure to dust in an industrial unit of producing China Clay. Occup Med. 2019. https://doi.org/10.18502/tkj.v11i3.2584
29. Mohammadi Kaji S. Survey of air pollution and health risk assessment at welding electrodes production process and proposal of control actions. Shahid Sadoughi University of Medical Sciences. department of Health. Master. 2014.