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Original Article

Investigating the mortality risk of silicosis and lung cancer in foundry workers in Urmia, Iran

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Abstract

Background & Aims**:** The correlation between silicosis and elevated susceptibility to lung cancer, chronic obstructive pulmonary disease, and autoimmune disorders is well-established. Hence, it is imperative to thoroughly analyze the potential health risks posed by exposure to crystalline silica within the foundry industry. Therefore, the present study aimed to evaluate the mortality rate associated with silicosis and lung cancer among workers in a foundry industry located in Urmia city in 2021.

Materials & Methods**:** The concentration of crystalline silica in the air was determined using Fourier transform infrared spectroscopy (FTIR) in accordance with NIOSH 7602. Estimating the excess lifetime risk of mortality and rate of silicosis-related mortality was performed using Rice et al. and Mannetje et al. models.

Results**:** The average concentration of crystalline silica in six occupational groups ranged from 0.029 to 0.064 $mg.m^{-3}$. Among the six occupational groups studied, sand preparation workers were the most exposed to crystalline silica. According to the model of Mannetje et al., the cumulative exposure of 87% of people exposed to crystalline silica is in the range of 0 to 0.99, which indicates the death of one person per thousand people. Also, in this industry, the risk of dying from lung cancer was 15 per thousand people.

Conclusion**:** The findings indicate that the average concentration of crystalline silica in all occupational groups exceeded the permissible occupational exposure limit of 0.025 $mg.m^{-3}$ recommended by the Occupational Health Committee of Iran. Additionally, the estimated risk of death due to silicosis and lung cancer is also higher than the acceptable risk level. Therefore, the implementation of control measures against exposure to silica is highly recommended.

Keywords**:** Crystalline silica, Foundry, Health risk assessment, Silicosis, Lung cancer

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Introduction

Silica, SiO_2, is the predominant oxide compound in the Earth's crust, occurring in both crystalline and non-crystalline (amorphous) forms (1). Among the various crystal polymorphs of silica, quartz is the most abundant type and is commonly found in a wide range of rocks, particularly granites, sandstones, and sands (2). The crystalline structure of silica is significant due to its high stability, insolubility in water, and its reaction with oxygen upon fracturing, leading to the formation of fine dust particles. Consequently, the presence of these reactive species on the crystal surface largely contributes to the toxicity of inhaled crystalline silica particles (3, 4).

Exposure to respirable crystalline silica leads to harmful health effects, including silicosis, pulmonary tuberculosis, chronic obstructive pulmonary disease (COPD), lung cancer, autoimmune diseases, and kidney diseases (5). Inhalation of silica particles causes the development of pulmonary fibrosis, increasing the long-term risk of lung cancer (6). In October 1996, the International Agency for Research on Cancer (IARC) classified crystalline silica as a human carcinogen (group 1) (7). Silicosis, a common disease resulting from inhalation exposure to crystalline silica, is a fibrotic lung disease caused by the inhalation and deposition of dust containing silica (8). In 1995, the World Health Organization (WHO) and the International Labor Organization (ILO) initiated a campaign to eliminate silicosis worldwide by 2030 (9). According to the Global Burden of Disease (GBD) study in 2017, there were an estimated 11,300 deaths per year and 235,700 years of life lost due to silicosis (10).

It is estimated that approximately 1.7 million workers in the United States, 3.2 million people in Europe, 23 million workers in China, and 3 million workers in India are exposed to respirable crystalline silica (11-14). The exposure to crystalline silica dust poses a significant and crucial issue in foundry industries, particularly in sand casting, which is the most widely used casting method. Dust emissions, specifically crystalline silica dust, are prevalent in most production processes within foundry units. Consequently, the inhalation of these particles poses significant health risks. These particles are commonly generated and released during sand preparation, molding, core making, melting and pouring, and knockout. The primary source of crystal silica dust emission occurs during the stages of sand preparation and molding (15). Numerous studies conducted in foundry industries have consistently demonstrated that foundry workers are exposed to higher levels of respirable crystalline silica (16-19).

In recent years, risk assessment in the field of occupational disease control has gained significant attention. Occupational risk assessment is a method used to estimate the health risks associated with varying levels of hazards in the workplace. It is crucial to determine the extent of health risks posed by hazards in order to appropriately eliminate, control, and reduce these risks (20). Mannetje et al. reported that the rate of silicosis-related mortality per 1,000 persons exposed increased almost linearly with cumulative exposure (21). They categorized cumulative silica exposure into different ranges, from 0 to 1.28 $mg.m^{-3}$ per year, and reported the relative risk of silicosis-related mortality ranging from 1 to 63 deaths per thousand exposures, depending on the cumulative exposure range. According to the guidelines set by Occupational Safety and Health Administration (OSHA), the acceptable risk level for silicosis is one case per thousand exposed individuals (22). According to the model, the relative risk of silicosis-related mortality, after 45 years of exposure to 0.1 $mg.m^{-3}$ of crystalline silica, was reported to be approximately 13 cases per thousand individuals up to the age of 65 (23). Rice et al. presented an assessment of the risk of lung cancer among workers exposed to crystalline silica using their own model (24). They predicted an excess lifetime risk of mortality from lung cancer based on 45 years of exposure with a lag of 10 years. Their model indicates that the excess lifetime risk, as per the current OSHA standard for respirable crystalline silica exposure (0.05 $mg.m^{-3}$), is estimated to be 19 cases per thousand individuals (25). The studies conducted in small foundries in Pakdasht, Tehran, showed that the death rate due to silicosis ranged from 1 to 13.7 cases per thousand individuals, while the death rate due to lung cancer ranged from 4 to 16 cases per thousand individuals (26). Furthermore, research conducted in the core making unit of a foundry industry revealed that the death rate from silicosis ranged from 6 to 63 cases per thousand individuals, and the death rate from lung cancer was 65 cases per thousand individuals (27). In developed countries, the incidence of silicosis is decreasing due to improved working conditions and dust control measures. However, in developing countries, exposure to crystalline silica dust remains a significant health problem (28). Therefore, understanding the exposure of workers to respirable crystalline silica dust in workplace air is of utmost importance to protect the health of workers. Based on these considerations, this study aimed to determine the level of workers' exposure to crystalline silica in different job groups and assess the risk of mortality from silicosis and lung cancer in a foundry located in Urmia city.

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Materials & Methods

Air Sampling and crystalline silica determination:

This study was a cross-sectional investigation that focused on workers in a foundry factory located in Urmia, Iran. The sample size was determined in accordance with the NIOSH Occupational Exposure Sampling Strategy Manual (29). According to this guide, similar exposure groups (SEG) were determined first. Then, the number of samples needed for each SEG was determined. Based on the workers' tasks, work processes, and pollutant emissions, the researchers divided them into six SEGs: sand preparation, melting and pouring, molding, core making, knockout, and grinding operators. According to the guideline, at least 15 samples of crystalline silica were required for each group. In total, 90 samples (15 × 6 = 90) of crystalline silica were collected from the workers' breathing zone.

To determine the level of exposure to crystalline silica dust, NIOSH 7602 method (30) was utilized. Air samples were collected from the workers' breathing zone using personal sampling pumps (SKC Ltd, Deluxe 224-PCMTX8, UK) connected to SKC plastic cyclones (Model 225–69,SKC Inc) containing 25mm polyvinyl chloride (PVC) filters with a 0.5-micron pore size. Prior to use, the PVC filters were placed in a desiccator for 24 hours to remove any moisture. The filters were then placed inside the plastic cyclones and connected to the worker's collar. The pump operated at a flow rate of 3 liters per minute and was calibrated by an electronic calibrator (BIOS DryCal DC-Lite, US) prior to each sampling. Sampling was carried out for 4 hours in the workplace.

The Fourier transform infrared technique was employed to quantify the concentration of crystalline silica in the air samples. Initially, each filter was put into a pristine porcelain crucible and subjected to ashing at 800°C in an oven for a duration of 2 hours. Subsequently, the resultant ash was blended with 300 mg of potassium bromide (KBr) (Sigma-Aldrich, Germany) to achieve homogeneity. This uniform mixture was then introduced into 13 mm metal molds and pressed using a press machine at a pressure of 20 MPa for 2 minutes to form tablets. The prepared tablets were scanned in a FTIR (WQF-510A, Rayleigh, China) in the wavenumber range of 400-4000 cm^{-1} and in the region of 710-825 cm^{-1} to determine the crystalline silica. Using the absorbance values in the calibration curve formula, obtained from the standard samples, the amounts of crystalline silica in the desired samples were calculated.

Risk assessment:

In this study, the risk of mortality due to silicosis was estimated using the model developed by Mannetje et al. based on the cumulative exposure of workers to crystalline silica over a 10-year period (31). The model takes into account cumulative exposure levels ranging from 0 to 0.99 $mg.m^{-3}$ per year to more than 28.1 $mg.m^{-3}$ per year. To evaluate the risk of death due to silicosis, the cumulative exposure of each worker was calculated and then inserted into the model. In addition, the risk of mortality due to lung cancer for workers exposed to crystalline silica was calculated using the linear regression model developed by Rice et al., assuming 45 years of exposure. The equation used for this calculation was as follows (24, 25):

$$A = 0.77 + 373.69 \times GM$$

A: risk of death from lung cancer

GM: geometric mean of crystalline silica concentration

In order to calculate descriptive statistics and analytical statistics, SPSS software (version 16) was used.

Results

The level of exposure to crystalline silica varies significantly among different tasks of foundry work (Table 1). Sand preparation workers had the highest exposure to crystalline silica, with an average of 0.064 (± 0.042) $mg.m^{-3}$, which is more than twice the recommended limit. In contrast, melting and pouring workers had the lowest exposure to crystalline silica, with an average concentration of 0.029 (± 0.012) $mg.m^{-3}$, which is slightly above the recommended limit. The average exposure for all job groups of foundry workers, 0.046 (± 0.043), was higher than the recommended limit of 0.025 $mg.m^{-3}$ set by the Iranian occupational health committee and American Conference of Governmental Industrial Hygienists (ACGIH). This indicates a potential risk of developing health problems related to crystalline silica exposure for workers in this industry (Table 1).

Table 1. Respirable crystalline silica dust in foundry job groups

Job groups	C ($mg.m^{-3}$)					
	AM [a]	SD [b]	GM [c]	GSD [d]	Min	Max
Sand preparation	0.064	0.042	0.053	1.906	0.018	0.167
Molding	0.058	0.088	0.038	2.110	0.017	0.370
Core making	0.046	0.019	0.043	1.496	0.023	0.092
Melting and pouring	0.029	0.012	0.028	1.479	0.013	0.050
Knockout	0.042	0.021	0.037	1.632	0.017	0.089
Grinding	0.037	0.018	0.033	1.629	0.014	0.074

[a] arithmetic mean, [b] standard deviation, [c] geometric mean, [d] geometric standard deviation

Table 2 presents the findings of the mortality risk associated with silicosis in the foundry industry, using the application of Mannetje et al.'s model. The analysis reveals that the highest relative risk is in cumulative exposure of 0 to 0.99 $mg.m^{-3}$ per year, resulting in a risk estimate of 87 cases per 1000 individuals.

Table 2. Risk of mortality caused by silicosis among foundry workers, based on Mannetje et al. model.

Cumulative exposure	Relative risk of silicosis-related mortality according to Mannetje et al. model	Number of worker No. (%)
0 - 0.99	1	87 (96.7)
0.99 - 1.97	3.4	2 (2.2)
1.97 - 2.87	6.2	0 (0)
2.87 - 4.33	9.4	1 (1.1)
4.33 - 7.12	13.7	0 (0)
7.12 - 9.58	22.6	0 (0)
9.58 - 13.21	24	0 (0)
13.21 - 15.89	40.2	0 (0)
15.89 - 28.1	25.1	0 (0)
> 28.1	63.6	0 (0)

Table 3 presents the results of mortality risk associated with lung cancer in foundry workers, determined by the Rice et al.'s model. According to Table 3, the estimated mortality risk for lung cancer is 15 cases per 1000 individuals (ranged from 11 to 21) within the exposure range of 0.029-0.064 $mg.m^{-3}$.

Table 3. Risk of mortality caused by lung cancer among the foundry workers based on Rice model.

Job groups	Number of air samples	Geometric mean (mg.m^{-3})	The excess lifetime risk of mortality due to lung cancer
Sand preparation	15	0.053	21
Molding	15	0.038	15
Core making	15	0.043	17
Melting and pouring	15	0.028	11
Knockout	15	0.037	15
Grinding	15	0.033	13
Total	90	0.038	15

Discussion and conclusion

The current investigation aimed to explore the level of occupational exposure to crystalline silica dust among workers in a foundry industry and to assess the associated risk of lung cancer and silicosis mortality. The average concentration of crystalline silica observed in this study was nearly twice as high as the established standards defined by Iran and ACGIH. These results are in line with a prior study conducted by Omidiandost et al., which evaluated the occupational exposure to general dust and crystalline silica dust in the foundries of Pakdasht city in Tehran, Iran. Their study also demonstrated higher levels of exposure to crystalline silica compared to the occupational standards set by the Occupational Health Committee of Iran and ACGIH, further corroborating the findings of the present investigation (18). Azari et al. (25) and Mohammadian et al. (32) determined the exposure to crystalline silica among workers in various industries, including the foundry industry. They reported an average silica exposure of 0.034 mg.m^{-3} for foundry industry workers. In agreement with the present study the level of exposure exceeds the permissible limit recommended by the Iranian occupational exposure limit and ACGIH threshold limit value (25, 32). Furthermore, Andersson et al. evaluated the levels of occupational exposure to respirable dust and quartz in 11 iron foundries located in Sweden. The results of respirable quartz indicated that 23% of all measurements exceeded the occupational exposure limit set by the European Union (EU-OEL = 0.05 mg.m^{-3}), and 56% of all measurements surpassed the ACGIH standard (16).

The level of exposure to crystalline silica in occupational groups in the foundry plant was ranked as follows: sand preparation workers > molding workers > core making workers > melting and pouring workers > knockout workers. These findings were in line with the findings reported by Ayalp et al., which demonstrated the higher exposure of foundry workers to silica, specifically in sand preparation, molding, and shakeout (33). Similarly, Tong et al.'s study indicated that workers were exposed to crystalline silica during various processes, namely melting, cast shakeout and finishing, sand preparation, molding, and core making in descending order (34). The variations in the levels of crystalline silica exposure among foundry workers across the globe can be attributed to several disparate factors. These may include differences in the availability and efficacy of industrial hygiene control measures, the work practices of workers, the level of workplace housekeeping, and variations in study methodologies.

Considering the limitations of comparing workers' exposure to health standards in providing a comprehensive understanding of their health status, the present study adopts risk assessment methods to evaluate the incidence of silicosis and lung cancer. Utilizing the Mannetje model and a classification system based on cumulative exposure to crystalline silica, the study estimates a mortality rate for silicosis ranging from 6 to 63 cases per thousand individuals. It is worth noting that the acceptable risk level for silicosis, as per OSHA standards, is set at one case per thousand individuals. Consequently, the analysis reveals that 97.7% of the workers fall within the acceptable risk range, while 3.3% exceed the acceptable threshold, signifying an unacceptable risk level. In a prospective study encompassing 3010 Chinese workers, a real risk assessment regarding silicosis demonstrates that 33.7% of the workers exhibit symptoms of the disease. Among these affected individuals, approximately 69% have been cumulatively exposed to a concentration of 5.4 mg.m-^{3} of crystalline silica dust. It is noteworthy that the calculated risks from the Chinese study surpass those observed in the present study (35).

In general, the risk assessment model employed in this study for estimating mortality risk associated with silicosis may result in lower risk estimates compared to previous prospective studies (25). Utilizing the model proposed by Rice et al., the risk of death from lung cancer was determined to range from 11 to 21 cases per thousand individuals exposed to crystalline silica. According to the linear regression analysis of this model, the frequency of lung cancer mortality risk from 45 years of exposure to 0.05 mg.m-^{3} of crystalline silica (the previous threshold value recommended by ACGIH) is estimated at 19 cases per thousand individuals. Recently, ACGIH has revised this threshold value to 0.025 mg.m-^{3}, thereby reducing the risk of death from lung cancer to 10 cases per thousand individuals (36). However, it should be noted that this level of crystalline silica exposure may not ensure the desired level of safety for achieving an acceptable risk level of one case per thousand exposed individuals (22, 37).

In the studies conducted within the small foundries of Pakdasht city in Tehran, the mortality rate attributed to silicosis was estimated to range from 1 to 13.7 cases per thousand individuals. Additionally, the mortality rate associated with lung cancer was estimated to range from 4 to 16 cases per thousand individuals (26). Furthermore, a study conducted by Zarei et al. in the core-making unit of a foundry industry revealed that the mortality rate resulting from silicosis ranged from 6 to 63 cases per thousand individuals, while the mortality rate associated with lung cancer was reported to be 65 cases per thousand people (27). These findings indicate higher mortality rates for both silicosis and lung cancer compared to the present study. These disparities in results could potentially be due to variations in sample size and levels of exposure to crystalline silica across the studies. In accordance with the principle of acceptable lifetime risk, defined as one person per thousand individuals exposed to crystalline silica, the risk assessment conducted in the present study indicate a substantial level of risk for foundry workers. This heightened risk carries the potential for significant compensation payments to be incurred by employers and the country's insurance system.

Hence, to effectively prevent and control the exposure to crystalline silica dust within the foundry setting, a combination of engineering controls (e.g., employing ventilation systems and wet methods), utilization of personal protective equipment (e.g., wearing protective masks), implementation of administrative controls, emphasis on good housekeeping practices, comprehensive training programs, and adoption of improved work practices can be employed (38). This study is subject to certain limitations, notably the relatively small number of sampling sites and the absence of an investigation into the association between smoking and the development of silicosis and lung cancer. It is strongly recommended that future research be conducted within larger-scale foundries to address these limitations and obtain more robust findings.

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Conflict of interest

The authors have no conflict of interest in this study.

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Data availability

The raw data supporting the conclusions of this article are available from the authors upon reasonable request.

References

1. Pa FC, Abdullah C, Fazlul B, editors. Review of extraction of silica from agricultural wastes using acid leaching treatment. Advanced Materials Research; 2013: Trans Tech Publ.
2. Wray RAL, Sauro F. An updated global review of solutional weathering processes and forms in quartz sandstones and quartzites. Earth-Science Reviews. 2017;171:520-57. https://doi.org/10.1016/j.earscirev.2017.06.008
3. OSHA. Occupational exposure to respirable crystalline silica-review of health effects literature and preliminary quantitative risk assessment. OSHA Publication Washington, DC, USA. 2010:1-399.
4. WHO. IARC Monographs, volume 68: silica-summary of data reported and evaluation. 2000.
5. Cheepsattayakorn A, Cheepsattayakorn R. Silicosis-Associated Tuberculosis: Management and Control. American Journal of Public Health Research. 2022;6(2):125-9.
6. Poinen-Rughooputh S, Rughooputh MS, Guo Y, Rong Y, Chen W. Occupational exposure to silica dust and risk of lung cancer: an updated meta-analysis of epidemiological studies. BMC public health. 2016;16(1):1-17. https://doi.org/10.1186/s12889-016-3791-5
7. IARC. IARC monographs on the evaluation of carcinogenic risks to humans: silica, some silicates, coal dust, and paraaramid fibrils. World Health Organization, International Agency for Research on Cancer. 1997;68.
8. Greenberg MI, Waksman J, Curtis J. Silicosis: a review. Disease-a-Month. 2007;53(8):394-416. https://doi.org/10.1016/j.disamonth.2007.09.020
9. WHO. Elimination of silicosis. GOHNET Newsletter. www who int/entity/occupational_health/publications/newsletter/gohnet12e pdf. 2007.
10. Roth GA, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N, et al. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980-2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2018;392(10159):1736-88. https://doi.org/10.1016/S0140-6736(18)32203-7
11. Jindal SK. Silicosis in India: past and present. Current Opinion in Pulmonary Medicine. 2013;19(2):163-8. https://doi.org/10.1097/MCP.0b013e32835bb19e
12. Kauppinen T, Toikkanen J, Pedersen D, Young R, Ahrens W, Boffetta P, et al. Occupational exposure to carcinogens in the European Union. Occupational and environmental medicine. 2000;57(1):10-8. https://doi.org/10.1136/oem.57.1.10
13. Ministry of Health of the People's Republic of China. Chinese annual health statistical report Beijing: Ministry of Health of the People's Republic of China 2009.
14. NIOSH. Health Effects of Occupational Exposure to Respirable Crystalline Silica: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2002.
15. Iran Ministry of Health & Medical Education. A Guide to Occupational Health in Foundries Islamic Republic of Iran Ministry of Health and Medical Education Enviromental and Occupational Health Center; 2012.
16. Andersson L, Bryngelsson IL, Ohlson CG, Nayström P, Lilja BG, Westberg H. Quartz and dust exposure in Swedish iron foundries. Journal of occupational and environmental hygiene. 2008;6(1):9-18. https://doi.org/10.1080/15459620802523943
17. Kuo CT, Chiu FF, Bao BY, Chang TY. Determination and prediction of respirable dust and crystalline-free silica in the taiwanese foundry industry. International journal of environmental research and public health. 2018;15(10):2105. https://doi.org/10.3390/ijerph15102105
18. Omidianidost A, Ghasemkhani M, Azari MR, Golbabaei F. Assessment of occupational exposure to dust and crystalline silica in foundries. Tanaffos. 2015;14(3):208-12.

19. Yassin A, Yebesi F, Tingle R. Occupational exposure to crystalline silica dust in the United States, 1988-2003. Environmental health perspectives. 2005;113(3):255-60. https://doi.org/10.1289/ehp.7384
20. NIOSH. Occupational Risk Assessment: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2017 [Available from: https://www.cdc.gov/niosh/topics/riskassessment/default.html.
21. Steenland K, Attfield M, Boffetta P, Checkoway H, DeKlerk N, Koskela R. Exposure-response analysis and risk assessment for silica and silicosis mortality in a pooled analysis of six cohorts. Occupational and environmental medicine. 2002;59(11):723-8. https://doi.org/10.1136/oem.59.11.723
22. Rodricks JV, Brett SM, Wrenn GC. Significant risk decisions in federal regulatory agencies. Regulatory Toxicology and Pharmacology. 1987;7(3):307-20. https://doi.org/10.1016/0273-2300(87)90038-9
23. Sherson D. Silicosis in the twenty first century. BMJ Publishing Group Ltd; 2002. p. 721-2. https://doi.org/10.1136/oem.59.11.721
24. Rice F, Park R, Stayner L, Smith R, Gilbert S, Checkoway H. Crystalline silica exposure and lung cancer mortality in diatomaceous earth industry workers: a quantitative risk assessment. Occupational and environmental medicine. 2001;58(1):38-45. https://doi.org/10.1136/oem.58.1.38
25. Azari MR, Rokni M, Salehpour S, MEHRABI YE, Jafari MJ, NASER MA, et al. Risk assessment of workers exposed to crystalline silica aerosols in the east zone of Tehran. 2009.
26. Omidianidost A, Ghasemkhani M, Kakooei H, Shahtaheri SJ, Ghanbari M. Risk assessment of occupational exposure to crystalline silica in small foundries in Pakdasht, Iran. Iranian journal of public health. 2016;45(1):70.
27. Zarei F, R Azari M, Salehpour S, Khodakarim S, Kalantary S, Tavakol E. Exposure assessment of core making workers to respirable crystalline silica dust. Health and Safety at Work. 2017;7(1):1-8.
28. De Vuyst P, Camus P. The past and present of pneumoconioses. Current opinion in pulmonary medicine. 2000;6(2):151-6. https://doi.org/10.1097/00063198-200003000-00012
29. Leidel NA, Busch KA, Lynch JR. Occupational exposure sampling strategy manual: US Department of Health, Education, and Welfare, Public Health Service, National Institute for Occupational Safety and Health. Publication no. 77-173; 1977.
30. Andrews R, O'Connor PF. NIOSH manual of analytical methods (NMAM), 5th Edition. 5th ed. Washington D.C., USA: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2020.
31. 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
32. Mohammadyan m, Rokni M, Islami S, Fazeli A. Evaluation of Workers' Exposure to Crystaline Silica Particles in Some Factories of Mazandaran Province. Journal of Mazandaran University of Medical Sciences. 2012;22(88):17-24.
33. Ayalp A, Myroniuk D. Evaluation of occupational exposure to free silica in Alberta foundries. American Industrial Hygiene Association Journal. 1982;43(11):825-31. https://doi.org/10.1080/15298668291410648
34. Tong R, Cheng M, Ma X, Yang Y, Liu Y, Li J. Quantitative health risk assessment of inhalation exposure to automobile foundry dust. Environmental geochemistry and health. 2019;41(5):2179-93. https://doi.org/10.1007/s10653-019-00277-8
35. Chen W, Zhuang Z, Attfield M, Chen B, Gao P, Harrison J, et al. Exposure to silica and silicosis among tin miners in China: exposure-response analyses and risk assessment. Occupational and environmental medicine. 2001;58(1):31-7. https://doi.org/10.1136/oem.58.1.31
36. ACGIH. The Documentation of the Threshold Limit Values and Biological Exposure Indices for Chemical Substances and Physical Agents & Biological Exposure

Indices. Silica, Crystalline-Quartz. 7th ed. Cincinnati: American Conference of Governmental Industrial Hygienists; 2001.

37. ACGIH. The Documentation of the Threshold Limit Values and Biological Exposure Indices for Chemical Substances and Physical Agents & Biological Exposure Indices: American Conference of Governmental Industrial Hygienists; 2007.

38. Sahihazar ZM, Ghahramani A, Galvani S, Hajaghazadeh M. Probabilistic health risk assessment of occupational exposure to crystalline silica in an iron foundry in Urmia, Iran. Environmental Science and Pollution Research. 2022;29(54):82014-29. https://doi.org/10.1007/s11356-022-21487-1