Occupational Risks in the Extraction and Processing of Mineral Raw Materials

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Abstract. The aim of this paper was to assess the man-made risks arising in the process chain from the extraction of primary raw materials in the form of quartzite and its further processing into the final product in the form of silicon. As the objects of research, we chose quartzite extracting enterprises, Cheremshansk Quartzite Mine and Kremny JSC which processes quartzite into silicon. To assess the occupational risk, we applied the method of assessing the individual occupational risk (IOR) level developed by the Klin Institute of Occupational Safety and Working Conditions. As a result, it was established that, in general, the level of occupational risks in the extraction of quartzite corresponds to the “average” level of risk. The occupation of Screener was classified to have the highest level of IOR (0.2). For the most part, a significant contribution to the level of occupational risk for the considered occupations is made by the dust factor, as well as for the occupations connected with the steering of large-sized machines - by general vibration. In the processing of quartzite, the IOR level corresponds to the “average” level of risk in most occupations. However, for some of the workers, the risk level is set to the “high” value. This is due to significant concentrations of dust in the air of the working area, as well as unfavorable microclimate parameters.

1. Introduction

Due to the development of modern high-tech production, mainly the semiconductor industry, the demand for silicon is steadily increasing. Silicon (Si) is a quite common element on our planet (about 27.6% of the mass of the earth's crust), but as such it does not occur in nature in its pure form, since Si forms strong compounds with oxygen and carbon. Why Si? The use of Si at the present stage is indisputable and diverse, it is used in the following capacities: as a raw material for the metallurgical industry (as a component of alloys, as a deoxidizer, a modifier of metal properties or an alloying element); for the production of pure polycrystalline silicon or purified metallurgical silicon (Si_met); for the production of silanes; for the production of solar cells; in the plastics industry, and is the basis of modern electrical engineering (used for the production of transistors, photovoltaic cells, integrated circuits, etc.) [1].

Since the demand for such a unique material is increasing, so is the demand for raw materials, and therefore for high-purity quartz raw materials. According to the results of geological research, quartz is the most common mineral in the earth's crust. It has high hardness: hexagonal (α-quartz), stable at a pressure of 0.2 MPa in the temperature range of 870-573 °C and trigonal (β-quartz), stable at a temperature below 573 °C, the most widely occurring in nature [2].
Quartzite is a rock that is mainly formed by quartz grains (from 0.1 to 1 mm) which are similar in structure and form a solid mass with a splintery or shell-like fracture. In addition to quartz, other minerals are often found in quartzite: corundum ($\text{Al}_2\text{O}_3$), topaz ($\text{Al}_2[\text{F,OH}]_2[\text{SiO}_4]$), rutile ($\text{TiO}_2$), hematite ($\text{Fe}_2\text{O}_3$), which are included in quartz grains or pressed between them in the form of clay, earth, gangue, etc. [3, 4].

Eastern Siberia also has large deposits of quartz: in the Mamsko-Chuysky Municipality of the Irkutsk Region ($\text{SiO}_2$ content up to 99.981%); in the Okinsky Municipality of Buryatia - the Bural-Sardyk field; the Novopavlovsk and Cheremshansk fields (Buryatia) [5]. However, quartz raw materials containing not less than 98% $\text{SiO}_2$ are used for silicon production.

The technological process of extraction and processing of quartzite is characterized by the probability of negative consequences for the life and health of personnel or occupational risks. The aim of our work is to assess the man-made risks arising in the process chain from the extraction of primary raw materials in the form of quartzite and its further processing into the final product in the form of silicon.

### 2. Object of research

As the objects of research, we chose quartzite extracting enterprises, Cheremshansk Quartzite Mine, a branch of Kremny JSC, and Kremny JSC itself which processes quartzite into silicon.

The Cheremshansk field is located in the Pribaikalsky Municipality, the Republic of Buryatia, 60 km from Ulan-Ude and the Mostovaya railway station. The explored reserves of quartzites in this field amount to 46.3 million tons with an insignificant content of hazardous impurities: iron oxides, aluminum, calcium, total forecast resources - approximately 100 million tons. The development of the field is carried out by Cheremshansk Quartzite Mine, a branch of Kremny JSC.

According to production data, Cheremshansk Quartzite Mine is developing this field with an annual production capacity of up to 427 thousand tons. Mining operations are carried out by the open method using drilling and blasting technology, in other words, the extraction of the ore body occurs by separating the rock mass from the massif with the blast energy, followed by transportation to the crushing and screening plant for primary processing. The main consumer of the output is Kremny JSC.

Kremny JSC was commissioned in 1981 and is the only manufacturer of refined silicon in Russia. It produces silicon in three-phase ore smelting furnaces with a capacity of 16.5 MVA and 25 MVA. According to production data, the production volume of Kremny JSC in 2018 amounted to 36 thousand tons.

The results of multiple studies devoted to the working conditions of employees at quartzite extracting and processing enterprises and the carbothermic process for obtaining silicon have repeatedly confirmed the presence of a combination of multifactor negative effects on workers, resulting in significant negative consequences for humans in the form of production environment factors such as fibrogenic aerosols, gas pollution, production noise, general and local type vibrations, different types of radiation, adverse microclimate, etc., levels and concentrations of which almost for all workers of these enterprises do not meet regulatory requirements. Therefore, there is a need to carry out the occupational risk assessment [7-13].

### 3. Research methods

There are many various methods of occupational risk assessment unique in their essence, which have both advantages and disadvantages, and also differ in complexity of application. One of them was applied in our work, namely, a method of assessing the individual occupational risk (IOR) level [14].

In 2009, the Research Institute of Occupational Medicine of the Russian Academy of Medical Sciences, together with the Klin Institute of Occupational Safety and Working Conditions “OLS-complect”, developed a methodology for assessing IOR depending on the working conditions and health status of an employee. The methodology is based on determining the level of individual occupational risk, which is a combination of a set of indicators, such as age, individual characteristics of the health status of workers, and parameters of the production environment. The IOR method takes
into account cases of occupational diseases and injuries at the workplace. As a result of the calculation, we obtained a single-digit risk index.

Later, in connection with the adoption of the Federal Law “On the Special Assessment of Working Conditions” No. 426-FZ of December 28, the Klin Institute of Occupational Safety and Working Conditions adapted the method for assessing IOR to the requirements and conditions that were established by implementing the Federal Law No. 426-FZ.

The definition of the individual occupational risk of an employee is calculated by multiplying the weighted values of the parameters (working conditions, working experience of the employee in harmful and (or) hazardous working conditions, his age and health status) by the indicators of injury rate and morbidity in the workplace, and is presented in the formula:

\[ IOR = \text{SUM} \cdot I_m \cdot I_3 \]  \hspace{1cm} (1)

The totals of the weighted values of the parameters is determined by the following formula:

\[ \text{SUM} = V_1 \cdot \text{IAWC} + V_2 \cdot H + V_3 \cdot A + V_4 \cdot E \]  \hspace{1cm} (2)

where IAWC is an integral assessment of working conditions in the workplace;

H is an indicator of the health status of the employee;

A is an indicator of the age of the employee;

E is an indicator of the working experience of the employee in harmful and (or) hazardous conditions;

I_i is an indicator of the injury rate in the workplace;

I_m is an indicator of the occupational morbidity in the workplace;

V_i are coefficients that take into account the significance of factors and ensure the conversion of parameters into relative values.

We chose to use this method based on the uniqueness inherent in it, in the form of taking into account the working conditions of workers, together with their individual characteristics [15, 16].

4. Results and discussion

For the assessment, we used the results of the special assessment of working conditions, production control of the production environment parameters at the facilities under study. The measurements were carried out by organizations that have accredited laboratories, with calibrated measuring instruments according to the methods for assessing production factors approved by the law. In addition, we used information on health indicators and individual characteristics of each employee [17-20].

Occupational risk assessment was conducted for workers directly involved in the technological process of extracting and processing quartz raw materials. The calculation results are presented in the form of diagrams in Fig. 1 and 2.

As a result, it was established that, in general, the level of occupational risks in the extraction of quartzite corresponds to the “average” level of risk. The occupation of Screener (0.2) was classified to have the highest level of IOR, the occupation of Crusher Operator (0.19) ranked second. For the most part, a significant contribution to the level of occupational risk for the considered occupations is made by the dust factor, as well as - for the occupations connected with the steering of large-sized machines - by general vibration.
Figure 1. Graphic presentation of occupational risk values for employees of Cheremshansk Quartzite Mine obtained by the method of assessing IOR level.

Figure 2. Graphic presentation of occupational risk values for employees of Kremny JSC obtained by the method of assessing IOR level.

When processing quartzite, the situation is different. The IOR level corresponds to the “average” level of risk in most occupations. However, the risk level is set to the “high” value for the occupations of Smelter and Refractory Man. This is primarily due to the presence of significant concentrations of
dust in the air of the working area as well as unfavorable microclimate parameters (Smelter), and hand tools which are a source of local vibration (Refractory Man). When comparing the general level of risk in the performance of work related to the extraction and processing of silicon, it was established that in the course of processing the risk is an order of magnitude higher than when performing mining operations. The main reason for this difference is the specificity of the silicon production process.

5. Conclusion
Thus, it can be concluded that throughout the entire process chain (from raw material extraction to the final product - Si), a number of production factors arise that have a cumulative effect on operating personnel in the form of occupational risks. But risk assessment is only one of the stages of the occupational risk management procedure. It is also necessary to carry out a detailed study of the reasons that make a tangible contribution to the level of risk with the subsequent implementation of measures to eliminate them.

6. References
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