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Provision of Personal Protection Equipment, According to the Risk of Exposure to Harmful Industrial Factors During Copper-Polymetallic Ore Mining

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ABSTRACT

The article addresses the issue of providing personal protective equipment, taking into account the risk of exposure to harmful factors of production during the extraction of copper ore in ore deposits located at great depths, i.e., underground mining. The working conditions of miners are characterized by a complex of harmful production factors, which include, above all, high dust and gas pollution of the air and a heated microclimate. The investigation revealed that workers in underground mines are exposed to the harmful effects of chemical factors. The evaluation of working conditions based on microclimatic factors showed an excess of air temperature (4-12 times) and relative humidity (3-10 times) in the workplace. Mathematical data processing has shown that the distribution of dangerous and harmful factors is subject to polynomial dependence. Mathematical data processing showed that the distribution of hazardous and harmful factors is subject to polynomial dependence. Increased air temperatures at a number of production sites, air pollution with dust and gases require a revision of the list of personal protective equipment, depending on the class of working conditions, taking into account the established standards for output. The authors provide recommendations for the introduction of a new range of personal protective equipment, depending on the presence and degree of exposure to harmful factors of production.

1. INTRODUCTION

The extraction of copper polymetallic ores is mastered in two ways: open or closed. Each of the two methods has its own characteristics in terms of production and technological cycle, work organization and production equipment used. Ore mining underground is carried out at a depth of 500 m, sometimes up to 800-1500 m, which implies an aggravation of mining conditions and a deterioration of working conditions.

The difference between the production environment and the work process leads to a number of factors influencing production. In order to create and effectively operate an industrial safety system at enterprises, it is necessary to adequately assess the existing risks [1] and have the most complete information about the situation at work. Ensuring safe work also has its peculiarities in the provision of personal protective equipment.

Modern working conditions in mining are characterized by exposure to physical and chemical factors such as noise, dust, microclimate, vibration, etc., the values of which may exceed the permissible standards [2]. A necessary condition for ensuring safe working conditions and reducing the risk of developing occupational diseases is the modernization and improvement of mechanisms for providing personal protective equipment [3].

A number of scientific studies have addressed the evaluation of the impact of adverse chemical factors on mining and processing companies. The authors [4] found a correlation between occupational morbidity and environmental pollution, a holistic assessment of working conditions was made, an analysis of the working conditions of miners underground according to chemical factors was carried out, and air pollution by harmful and hazardous gases and dust was noted. As the depth of mining from ventilation shafts increases, the risk of gas pollution increases and, as a result, the rate of rarefaction of harmful gases and ventilation of workings decreases. The study by some authors [5] found that the most harmful gases in underground mines are carbon dioxide, hydrogen sulfide, methane and nitrogen oxides.

Banasiewicz et al. [6] analyzed the danger of nitrogen oxides, identified the sources of NOx emissions into the atmosphere of the mine. It was also found that diesel mining equipment has the greatest impact on air pollution.

Microclimatic conditions in underground mines also affect working conditions and, accordingly, workers' ability to work, work-related injuries and occupational diseases [7]. The authors [8] studied the problems of heating microclimate in underground mines. Exposure to heat stress is an important problem for the health, safety, and performance of miners working in underground mines [9].

It can be noted that in 2017 there were changes in the rules in the field of heat stress control at Polish mines [10]. A new index of "replacement climatic temperature" (SCT) has been introduced, which takes into account the assessment of safe operation in deep mines. In this regard, Polish researchers pay attention to the thermal insulation of clothing when assessing the heating microclimate in the workplace.

The results of the following work [11] showed that the most dangerous factor is the climatic hazard associated with the ever-increasing temperature of the rocks, which in Polish copper mines is up to 50°C.

The existing problems associated with the negative impact of the microclimate on the health of miners in the United States of America led to the development by the National Institute for Occupational Safety and Health (NIOSH) of the draft requirements and recommendations for the protection of the workers health exposed to overheating, which are mandatory for the employer [12]. This document contains recommendations and the reasons why they should be followed, and also shows the consequences of not following, resulting in deterioration of health with excessive overheating, which can lead to a decrease in the ability of the worker to withstand overheating (fitness level, lack of experience in working with overheating.

Currently, a large range of personal protective equipment (PPE) against overheating is being produced - from the simplest to the more complex, while the costs for their purchase and maintenance also vary. 4 types of PPE have been studied:

- water-cooled suit,
- air-cooled suit,
- vest with heat absorber,
- PPE against overheating using evaporative cooling [12].

In case of excessive heat exposure, a suitable method is applied to protect workers from overheating.

Microclimate parameters depend on many factors. First of all, it depends on the climatic conditions of the area in which the enterprise is located, the depth of occurrence and removal of workings from the air supply shafts [13]. Also, other authors [14] found that the air temperature in mine workings depends on the heat exchange of air with the mountain range and heat exchange due to heat sources.

One of the methods of dealing with negative factors is the use of personal protective equipment.

In this context, it was of interest to study the working conditions in terms of chemical and physical factors at the Orlovsky mine and to develop recommendations for improving the selection and use of personal protective equipment.

Thus, the scientific novelty of the research conducted is the following:

- for the first time, a comprehensive study of working conditions at workplaces in the Oryol mine for the extraction of copper-polymetallic ore was conducted;
- identification of the areas where workers are most exposed to harmful factors;
- an assessment of the workplaces of the main occupations at the enterprises was carried out with regard to the impact of chemical and microclimatic factors, and recommendations were made for amending the regulations on the issue of personal protective equipment.

2. OBJECT AND METHODS OF RESEARCH

The object of research is the Orlovsky mine (Orlovsky deposit), located on the territory of the East Kazakhstan region in the village of Zhezkent, 135 km northwest of the regional center Ust-Kamenogorsk and 40 km northeast of the district center Borodulikha. The mine produces polymetallic copper ore in closed form, the annual production is 1300 thousand tons of ore.

Mining operations for underground mining of copper ore at the Orlovsky mine include the following technological processes:

- opening of ore deposits;
- mining works;
- cleaning excavation;
- blasting, transportation, storage and use of explosive materials;
- maintenance of the roof and fastening of mine workings;
- transportation and delivery of ore, materials and equipment;
- ventilation of mine workings;
- drainage;
- power supply;
- operation of pressure vessels.

To date, the Orlovskoye field has been opened up to the 12th horizon by the centrally located shafts of the Orlovskaya and Skipovaya mines and the shafts of the Severnaya and Yuzhnaya mines located on the flanks.

The ore bodies are represented by complex interlayer deposits occurring at a depth of 70 to 1200 m from the surface.

The shaft of the mine "Orlovskaya" with a clear diameter of 6.5 m has been passed up to 12 horizons, equipped with two single-cage lifts and is used for lowering and raising people, materials, equipment and supplying fresh air in an amount of up to 230 m^3 /s.

The shaft of the mine "Skipovaya" with a clear diameter of 5 m was passed to the 12th horizon, equipped with a double-skip ore and single-skip rock lifts.

The shaft of the mine "Severnaya" with a clear diameter of 5 m has been passed to 11 horizons, equipped with a single-cage lift and serves to supply fresh air in an amount of up to 120 m^3/s and emergency lifting of people.

The shaft of the mine "Yuzhnaya" with a clear diameter of 5 m has been penetrated to the 10th horizon equipped with a single-cage lift and is used for issuing polluted air in an amount of up to 249 m3/s and for emergency lifting of people.

The shaft of the mine "Novaya" with a clear diameter of 7 m was driven to a depth of 100 m from the surface. Its further drilling has been suspended due to difficult hydrogeological conditions [15].

The Orlovsky mine includes mining sections No. 1, 2, 3, a mining section, a drilling and blasting section, a mine workings support section and a goaf backfilling section.

The number of employees is as of January 1, 2023 - 1085 people.

This work is based on the results of certification of workplaces and a hygienic assessment of working conditions for representatives of the main working professions of an underground mine. The studies included measurements of physical (temperature, relative humidity) and chemical (silicon dioxide, nitrogen dioxide, ammonia) factors of the working environment.

The study of the workplaces was carried out by instrumental methods using the following instruments: Noise and vibration meter "Assistant", instrument for monitoring the parameters of the air environment meteometer "MES -200A", luxmeter-UV/radiometer "TKA-PKM"/06, continuous monitoring "GANK-4AR".

The data obtained were compared with the established standards provided for by sanitary rules, hygienic standards approved in the manner determined by the state agency in the field of sanitary and epidemiological welfare of the population in accordance with the Code of the Republic of Kazakhstan "On the health of the people and the healthcare system" [16].

The actual state of working conditions at the workplace was determined based on the assessment of the class and degree of harmfulness and danger of the factors of the working environment and work process, as well as the equipment of workers with personal protective equipment (PPE) [17].

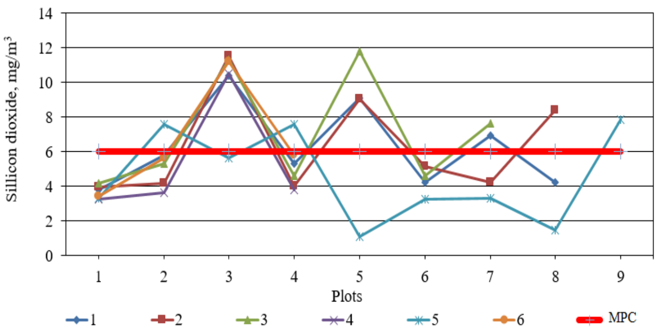
3. RESULTS AND DISCUSSION

The study of working conditions at workplaces was carried out in underground mines No. 1, 2, 3, in mines, drilling and blasting plants, mine buildings, vertical and horizontal mine transport of Orlovsky mine.

According to the results of certification of workplaces based on the levels of harmful production factors directly at the workplace, determined using instrumental measurements, the existing risks were identified.

The investigations revealed that workers in underground mines are exposed to the harmful effects of chemical factors. In the air of the working area, the dust content (silica) was increased by 1.73 times, the sulfur dioxide content by 1.65 times, the nitrogen dioxide content by 2 times, and the ammonia content by 2.1 times. At the drilling and blasting site, the permissible dust concentrations were found to be exceeded by 1.4-1.9 times. At the site of mine excavation, the maximum permissible values were found to be exceeded in dust content by 1.87 times, in sulfur dioxide content by 1.4 times, in nitrogen dioxide content by 1.75 times, and in ammonia content by 2.2 times. When assessing the state of working conditions at the workplaces of the sections of horizontal and vertical transport in the mine, a slight exceeding of the permissible norms for dust content by 1.3 times was found (Figure 1 to Figure 3).

The distribution of silicon dioxide concentration in the working area in all areas are shown in Figure 1.



1 - underground mining site No. 1; 2 - underground mining site No. 2; 3 - underground mining site No. 3; 4 - mining section; 5 - goaf backfilling section, 6 - mine workings support section

Figure 1. Silicon dioxide concentrations in the working area of the studied areas

According to the study [16], MPC for silicon dioxide is 6 mg/m^3. Based on Figure 1, we can conclude that in the working areas of the studied areas, the value of silicon dioxide released into the air of the working area during the transportation of the rock mass exceeds the standard value.

According to the results of the study, it can be concluded that the concentration of nitrogen dioxide (Figure 2) in the working area of the studied areas exceeds the standard value equal to 2 mg/m^3.

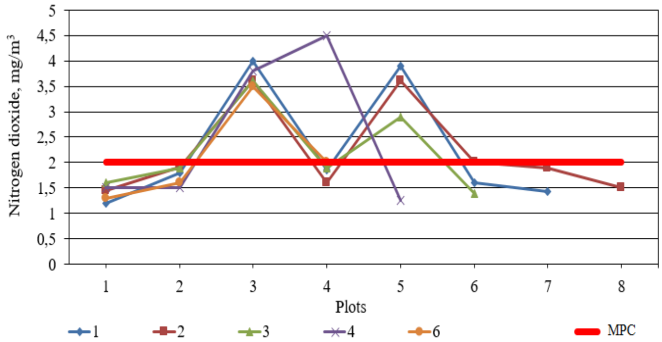


Figure 2. Concentrations of nitrogen dioxide in the working area of the studied areas

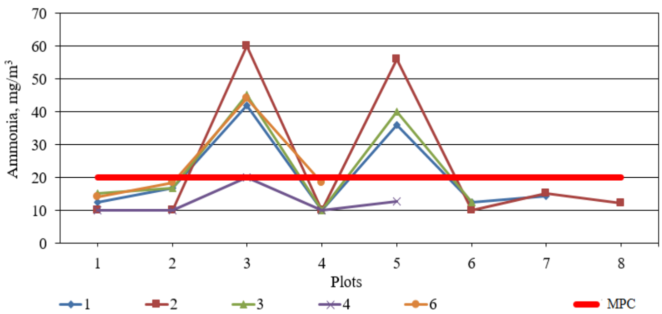


Figure 3. Ammonia concentrations in the working area of the studied areas

The results of the analysis of the conducted studies showed that in the mine sections, in addition to the working zone of the mining sections, there is an excess of ammonia (MPC-20 mg/m^3), due to blasting, where ammonium nitrate is used as an explosive substance.

Employees of the enterprise working in the following areas are exposed to the greatest impact of the harmful chemical factor: underground mining operations and mine workings support.

The results of the assessment of the state of working conditions at workplaces showed the excess of microclimatic factors (Figures 4 and 5) in some areas, in particular, the air temperature in the working area is 5-12°C higher than the norm.

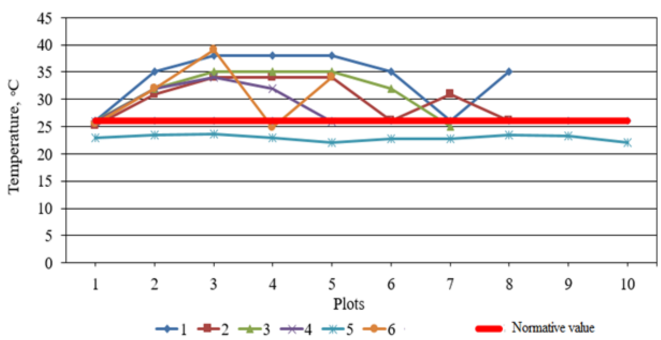


Figure 4. The temperature indicator of the working area of the studied areas

The indicators of relative humidity of the working area of the studied areas are shown in Figure 5.

Table 1. Evaluation of jobs for the main professions of the enterprise on the impact of chemical and microclimatic factors

Profession name	Air temperature in the working area, °C	Relative humidity, %	Nitrogen dioxide	Ammonia	Dust
Driller	3.2	3.2	3.1	3.1	3.1
Sinker	3.2	3.2	3.2	3.2	3.2
Miner	3.1	3.1	3.1	3.1	3.2
Ripper	3.1	3.1	3.1	3.1	3.1

Table 2. Assessment of the provision of PPE for the main professions of the mine

№	Name of PPE	Issuance rate per year (unit)	Availability of PPE in fact
1	Suit (jacket + dungarees / or trousers) made of cotton fabric with oil and water-repellent trim with reflective elements at chest level, sleeves and below the knees	1 set for 12 months	provided
2	Underwear	1 set for 6 months	provided
3	Cloth footcloths	2 pairs for 12 months	provided
4	Rubber boots with impact-resistant metal toe cap	1 pair for 12 months	provided
5	Boots made of genuine leather	1 pair for 12 months	provided
6	Protective helmet	1 piece for 36 months	provided
7	Helmet balaclava	1 piece for 12 months	provided
8	Respirator	1 piece for 1 shift	provided
9	Canvas mittens	1 pair for 1 month	provided
10	Anti-noise headphones (on duty)	before deterioration	provided
11	Goggles polycarbonate on duty	before deterioration	provided
12	Insulated cotton jacket with oil and water repellent finish, detachable lining with reflective elements at chest level and sleeves	1 item on belts	provided
13	Trousers made of cotton fabric with oil and water-repellent finish	1 product for belts	provided
14	Boots made of genuine leather (or tarpaulin) with a shock-resistant metal toe cap, insulated	1 product for belts	provided

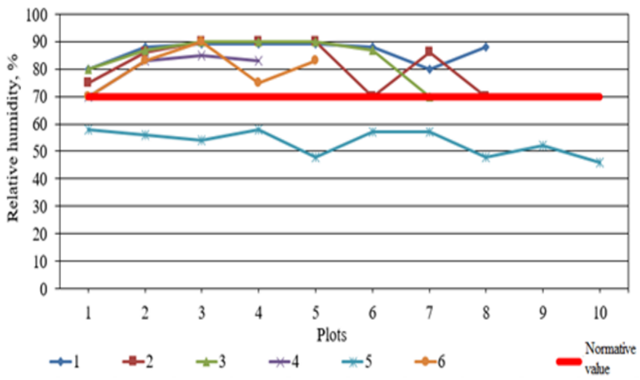


Figure 5. Indicators of relative humidity of the working area of the studied areas

The results of the assessment of the state of working conditions at the workplace also showed an excess of microclimatic factors in some areas:

- in the underground mining area No. 1, the air temperature in the working area is 9-12°C above the norm, the relative humidity is 8-9%;

- at the workplaces of the underground mining area No. 2, the air temperature is 5-8°C above the norm, the relative humidity is 6-10%;

- at the workplaces of the underground mining area No. 3 the air temperature is higher than the norm by 6-9°C, the relative humidity by 7-10%;

- at the workplaces of the mining section, the air temperature is 6-8°C higher than the norm, the relative humidity is 3-5%;

- at the workplaces of the drilling and blasting section, the air temperature is 4-6°C higher than the norm, the relative humidity is 3-4%;

- on the site of the pit fortification the air temperature is higher than the norm by 6-13°C, the air humidity by 3-10%.

The results of the analysis showed that in terms of air temperature and relative humidity in the working area, the goaf backfill sites do not exceed the standard values.

The evaluation of jobs in terms of the effects of chemical and physical factors in accordance with the occupation is shown in Table 1.

From Table 1, we can conclude that, according to the degree of production factors at the workplaces of the Orlovsky mine, mainly tunnellers who work in underground mining sites are exposed to harmful working conditions.

The assessment of the provision of PPE was carried out for each profession (drifter, fastener, underground miner) for all types of PPE based on a comprehensive check of compliance with the requirements for the availability of regulatory and technical documentation for the issuance of PPE with an indication of the norm [18]; the actual availability of PPE in accordance with the established norms for their issuance (Table 2); availability of quality certificates for the use of PPE.

An effective solution to protect the body of a miner from the complex of unfavorable environmental factors (gas-dust regime, microclimate) is the revision of personal protective equipment depending on the class of working conditions. Equipping workers with personal protective equipment is one of the employer's obligations in creating safe working conditions, regardless of the ownership form of the company.

In the Republic of Kazakhstan, more than 200 legal and administrative regulations (laws, instructions, lists, industrial standards for equipping workers with PPE, GOSTs, STBs, etc.) are in force in the field of PPE application. Mandatory is the application of the Technical Regulations of the Customs Union (Technical Regulations [19]), which establishes the requirements for the mandatory technical characteristics of PPE corresponding to the minimum permissible values and technical indicators of one or another factor of influence.

Confirmation of compliance of PPE with the requirements of the regulation is made in the form of a declaration and certification, depending on the degree of risk of harm to the user.

The legal basis for the use of PPE is enshrined in the Labor Code of the Republic of Kazakhstan, the Order on approval of the norms for issuing special clothing and other personal protective equipment to employees of organizations of various types of economic activity, approved by the Minister of Health and Social Development of the Republic of Kazakhstan dated December 8, 2015 No. 943 and other regulatory legal acts [18].

The rules for providing PPE in force in the Republic of Kazakhstan are based on the principle of regulation. However, the principle of rationing does not guarantee the safety of the worker, since the Model Norms for the free delivery of special clothing and other personal protective equipment, approved by the order of the Republic of Kazakhstan [18], do not classify according to the protective properties of PPE. Because of this, at a number of enterprises there is a discrepancy or incomplete correspondence of the PPE issued to the actual working conditions, primarily due to the lack of a methodology for assessing the effectiveness of the use of PPE in the workplace (in terms of protective properties, in terms of the correct choice of PPE). Model norms often cannot cover the specifics of each production. At individual workplaces, there may be an impact on the health of harmful factors that were not taken into account in the standard standards, but from which the employee must be protected. Therefore, it is required to take into account the influence of all production factors available at a particular workplace.

Currently, PPE is issued according to standard norms [18] without considering occupational risk.

In addition to the norms for issuing PPE for the main professions of an underground mine (Table 2), a new range of PPE is proposed depending on harmful production factors and the degree of their impact.

PPE for breathing:

- for working conditions of the 2nd class: respirator with filtration against aerosols. Respirator of protection class FFP1, filtering half masks (respirators) FFP1 [20];
- for working conditions of class 3.1: antiaerosol and antiaerosol with additional protection against gasses and vapors personal respiratory protection (PRP) with a filtering front part - filtering half masks. Respirator of protection class FFP2;
- for working conditions of class 3.2: insulating masks (masks, half masks, quarter masks), replaceable filters (filtering elements: antialcohol, antigas, combined), respirators of protection class FFP2 or reusable half masks with different replaceable filters according to the European standard EN 140:1998;
- for working conditions of classes 3.3 and 3.4: gas mask, respiratory protection class FFP3, insulating front parts (masks, half masks, quarter masks), replaceable filters (filter elements: anti-alcohol, anti-gas, combined).

PPE for eyes:

- for working conditions of class 2: protective glass: the transparent part of the personal eye protection that enables vision [21];
- for working conditions of class 3.1: protective goggles, closed protective goggles;
- for working conditions of class 3.2: safety goggles, visor goggles;
- for working conditions of class 3.3: safety goggles with direct ventilation: ventilated safety goggles, in the underground space of which the air enters without changing direction.

Special protective clothing:

- for working conditions of classes 3.1, 3.2, 3.3 and 3.4: clothing made of natural cotton fabrics with breathability, porosity, hygroscopicity, capillarity, low resistance to moisture evaporation, which reduce the heat load on the body, water-cooled suits, suits with air cooling, vests with cooling bodies, PPE against overheating with evaporative cooling [22, 23].

PPE for hands:

- for working conditions of class 2: fabric work gloves, semi-woven gloves, wool gloves, mittens [24];
- for class 3.1, 3.2, 3.3 and 3.4 working conditions: gloves, mittens.

Head PSA:

- for working conditions of 3.1, 3.2, 3.3, and 3.4: helmet, balaclava, cotton-based headgear with acid-alkali impregnation, cloth helmet instead of cotton headgear, headgear (kepi or beret) made of mixed fabric, protective head net, cotton-based headgear with antibacterial and antistatic impregnation, headgear against plague with antibacterial impregnation, sterile multilayer surgical headgear made of non-woven fabric.

Based on the analysis of existing problems in the provision and use of PPE in the workplace, it can be concluded that the effectiveness of PPE use in the workplace largely depends on their correct choice and application.

4. CONCLUSIONS

The article is devoted to the study of the working conditions of underground mine workers in the extraction of copper ore using the Orlovsky mine as an example. As part of the certification of workplaces, the working conditions of the leading working specialties employed in the extraction of copper ore were studied.

The investigations revealed that workers in underground mines are exposed to the harmful effects of chemical factors. Excess of dust (silica) (1.3-1.9 times), sulfur dioxide (1.4-1.65 times), nitrogen dioxide (1.75-2 times) and ammonia (2.1-2.2 times) were found in the air of the working area. The evaluation of the condition of working conditions based on microclimatic factors showed an excess of air temperature (4-12 times) and relative humidity (3-10 times) in the workplace.

The data obtained from the results of hygienic studies indicated that the overall assessment of working conditions for workers in the main professions engaged in the extraction of ore rock in underground conditions corresponded to the third hazardous class of the 1st–2nd degree of hazard (3.1–3.2).

One of the most important factors reducing the efficiency of field development is the sanitary and hygienic working conditions of miners. Excessive levels of the above-mentioned chemical and microclimatic factors, as well as noise in some workplaces, contribute to a high risk of injuries and occupational diseases in mining, 5-8 times higher than in other industries.

Particular attention is paid to the safety of miners and their health, since mining involves a high risk to life and health. Therefore, it is necessary to tighten the requirements for PPE, taking into account the degree of risk to health. For workers in mining, especially in the conditions of the underground

Orlovsky mine with its unfavourable chemical, microclimatic and sanitary-hygienic working conditions, it is important to choose PPE that provides reliable protection for workers.

The choice of a specific type of protective equipment for workers should be carried out taking into account the safety requirements for a given process or type of work. Personal protective equipment issued to employees must correspond to their gender, height and size, the nature and conditions of the work performed, and also ensure labor safety.

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REFERENCES

[1] Mouras, F., Badri, A. (2020). Survey of the risk management methods, techniques and software used most frequently in occupational health and safety. International Journal of Safety and Security Engineering, 10(2): 149-160. https://doi.org/10.18280/ijsse.100201

[2] Kruzhilko, O., Maystrenko, V., Tkalych, I., Polukarov, Y., Kalinchyk, V.P., Neklonskyi, I., Ryzhchenko, O. (2022). Study of the harmful factors influence on the occupational risk level: The example of the Ukrainian mining industry. Journal of Achievements in Materials and Manufacturing Engineering, 110(1): 35-41. https://doi.org/10.5604/01.3001.0015.7029

[3] Watson, C., Troynikov, O., Lingard, H. (2019). Design considerations for low-level risk personal protective clothing: A review. Industrial Health, 57(3): 306-325. https://doi.org/10.2486/indhealth.2018-0040

[4] Rebello, S., Anoopkumar, A.N., Aneesh, E.M., Raveendran, S., Parameswaran, B., Kim, S.H., Pandey A. (2020). Hazardous mineral mining: Challenges and solutions. Journal of Hazardous Materials, 402: 123474. https://doi.org/10.1016/j.jhazmat.2020.123474

[5] Strumiński, A., Madeja-Strumińska, B. (2020). Mine ventilation practice in Polish copper mines. In Mining in the New Millennium Challenges and Opportunities. CRC Press, pp. 173-179.

[6] Banasiewicz, A., Śliwiński, P., Krot, P., Wodecki, J., Zimroz, R. (2023). Prediction of NOx emission based on data of LHD on-board monitoring system in a deep underground mine. Energies, 16(5): 2149. https://doi.org/10.3390/en16052149

[7] Varghese, B.M., Hansen, A., Bi, P., Pisaniello, D. (2018). Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. Safety Scirnce, 110: 380-392. https://doi.org/10.1016/j.ssci.2018.04.027

[8] Roghanchi, P., Kocsis, K.C. (2018). Challenges in selecting an appropriate heat stress index to protect workers in hot and humid underground mines. Safety and Health at Work, 9(1): 10-16. https://doi.org/10.1016/j.shaw.2017.04.002

[9] Roy, S., Mishra, D.P., Bhattacharjee, R.M. (2022). Heat stress in underground mines and its control measures: A systematic literature review and retrospective analysis. Mining, Metallurgy and Exploration, 39: 357-383. https://doi.org/10.1007/s42461-021-00532-6

[10] Szlązak, N., Obracaj, D. (2019). Evaluation of Microclimate Conditions in Polish Underground Mines. In: Chang, X. (eds) Proceedings of the 11th International Mine Ventilation Congress. Springer, Singapore. https://doi.org/10.1007/978-981-13-1420-9

[11] Wróblewski, A., Banasiewicz, A., Gola, S. (2021). Heat balance determination methods for mining areas in underground mines-A review. Proceedings of the IOP Conference Series: Earth and Environmental Science, Surakarta, Indonesia, 24–25 August 2021, 942: 012011. https://doi.org/10.1088/1755-1315/942/1/012011

[12] Jacklitsch, B., Williams, W.J., Musolin, K., Coca, A., Kim, J.H., Turner, N., Cincinnati, O.H. (2016). NIOSH criteria for a recommended standard: Occupational Exposure to Heat and Hot Environments. https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf?id=10.26616/NIOSHPUB2016106.

[13] Mal'tsev, S.V., Semin, M.A. Kormshchikov, D.S. (2020). A method to determine aerodynamic drag coefficient in copper–nickel mine shafts. Journal of Mining Science, 56: 1032-1039. https://doi.org/10.1134/S1062739120060150

[14] Zaitsev, A., Shalimov, A., Borodavkin, D. (2023). Unsteady coupled heat transfer in the air and surrounding rock mass for mine excavations with distributed heat sources. Fluids, 8(2): 67. https://doi.org/10.3390/fluids8020067

[15] The project «Exploring and mining the lower horizons of the Orlovskoye field. Calculations and technical solutions to increase the productivity of the Orlovsky mine», Kazgiprotsvetmet, 2017 (in Russian).

[16] Code of the Republic of Kazakhstan dated 7 July 2020 No. 360-VI. On the health of the people and the healthcare system, https://adilet.zan.kz/eng/docs/K2000000360 (in Russ.)

[17] Abikenova, S., Daumova, G., Kurmanbayeva, A., Yesbenbetova, Z., Kazbekova, D. (2022). Relationship between occupational risk and personal protective equipment on the example of ferroalloy production. International Journal of Safety and Security Engineering, 12(5): 609-614. https://doi.org/10.18280/ijsse.120509

[18] Order of the Minister of Health and Social Development of the Republic of Kazakhstan dated December 8, 2015 No. 943. On approval of the norms for issuing special clothing and other personal protective equipment to employees of organizations of various types of economic activity, https://adilet.zan.kz/rus/docs/V1500012627

[19] Technical Regulations of the Customs Union TR CU 019/2011 On the safety of personal protective equipment (as amended on May 28, 2019) (in Russ.)

[20] GOST, 2016. 12.4.294-2015 (EN 149:2001+A1:2009) System of labor safety standards (SSBT). Personal respiratory protection. Half masks filtering for protection against aerosols. General technical conditions, <files.stroyinf.ru/Data2/1/4293762/4293762734.pdf>, accessed 01 June 2016 (in Russian).

[21] GOST, 1985. 12.4.013-85 (ST SEV 4564-84) System of labor safety standards (SSBT). Goggles. General technical conditions,

<files.stroyinf.ru/Data2/1/4294839/4294839019.pdf>, accessed 13 May 1985 (in Russian).
[22] GOST, 2020. ISO 11612-2020 Occupational safety standards system. Special clothing for protection against short-term exposure to an open flame, thermal radiation, convective heat, splashes of molten metal, contact with a heated surface. Specifications and test methods, <files.stroyinf.ru/Data/740/74013.pdf>, accessed 30 September 2020 (in Russian).
[23] GOST, 1983. 12.4.103-83 System of labor safety standards. Special protective clothing, personal protective equipment for legs and arms. Classification", <files.stroyinf.ru/Index2/1/4294851/4294851997.htm>, accessed 17 December 1983 (in Russian).
[24] GOST, 2019. EN 407-2012 System of labor safety standards. Personal protective equipment for hands. Gloves for protection against high temperatures and fire. Technical requirements. Test methods, <files.stroyinf.ru/Data2/1/4293781/4293781649.pdf>, accessed 1 May 2019 (in Russian).