UDC 622.87: 613.6.02
DOI: 10.21668/health.risk/2022.2.10.eng

Read online

Research article

OCCUPATIONAL HEALTH RISK FOR WORKERS FROM BASIC OCCUPATIONAL GROUPS EMPLOYED AT COPPER AND ZINC ORE MINING ENTERPRISES: ASSESSMENT AND MANAGEMENT

E.R. Shaykhlislamova[1,2], L.K. Karimova[1], N.A. Beigul[1], N.A. Muldasheva[1], A.Z. Fagamova[1], I.V. Shapoval[1], A.D. Volgareva[1], E.A. Larionova[1,3]

[1]Ufa Research Institute of Occupational Medicine and Human Ecology, 94 Kuvykina Str., Ufa, 450106, Russian Federation
[2]Bashkir State Medical University, 3 Lenina Str., Ufa, 450008, Russian Federation
[3]Ufa State Aviation Technical University, 12 K. Marksa Str., Ufa, 450008, Russian Federation

A great share of workers employed at polymetallic ores mining have to face harmful working conditions at their workplaces. To provide safe working conditions for them and to preserve their health is a vital task occupational medicine has to tackle.

Polymetallic ore mining enterprises employ certain common technological processes; nevertheless, there are specific features depending on ore mining techniques and the mineralogical composition of different ores. These features determine differences both in working conditions and in occupational risks of developing occupational morbidity (OM) and work-related morbidity (WRM).

By now, there have been enough studies on peculiarities of occupational health risks for workers employed at sulfide ore mines, copper-nickel ore mines and ferruginous quartzite mines. Considerably less attention has been given to assessing occupational risks for workers dealing with mining and processing copper-zinc ores.

We performed complex clinical and hygienic examinations at a major copper-zinc ore mining enterprise located in the Southern Urals. The research results gave grounds for determining a category of working conditions, establishing formation peculiarities and the structure of occupational and work-related diseases among workers from various occupational groups.

Occupational risks were assessed considering hygienic and medical-biological indicators.

We established the highest occupational health risks for shaft sinkers, followed by drilling unit operators, timberers, excavator drivers, load haul dumper (LHD) operators and underground self-propelled machine (USPM) operators.

The research results gave grounds for developing a conceptual model of assessing and managing occupational risks in the branch. The urgency of developing and implementing activities aimed at risk mitigation should be determined depending on how validated a risk is and on its rates established for specific occupational groups.

***Keywords:** occupational risk, workers, copper-zinc ores, ore mining, workers' health, hygienic and biomedical aspects.*

Elmira R. Shaikhlislamova – Candidate of Medical Sciences, director (e-mail: shajkh.ehlmira@yandex.ru; tel.: +7 (347) 255-19-57; ORCID: https://orcid.org/0000-0002-6127-7703).

Liliya K. Karimova – Doctor of Medical Sciences, Chief Researcher at the Department of Occupational Medicine (e-mail: iao_karimova@rambler.ru; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-4995-0854).

Natalya A. Beigul – Candidate of Chemical Sciences, Senior Researcher at the Department of Occupational Medicine (e-mail: omt_ufnii@mail.ru; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-8006-384X).

Nadezhda A. Muldasheva – Researcher at the Department of Occupational Medicine (e-mail: muldasheva51@gmail.com; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-3518-3519).

Alina Z. Fagamova – Junior Researcher at the Department of Occupational Medicine (e-mail: alinafagamova@gmail.com; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-6861-6886).

Inna V. Shapoval – Researcher at the Department of Occupational Medicine (e-mail: shapoval-inna@mail.ru; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-3258-2477).

Alfiya D. Volgareva – Candidate of Medical Sciences, Senior Researcher at the Department of Occupational Medicine (e-mail: ad-volgareva@yandex.ru; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-4875-1247).

Evelina A. Larionova – laboratory assistant at the Department of Occupational Medicine; undergraduate student of the Faculty of Civil Defense and Emergency Management (e-mail: larionova.evelina@mail.ru; tel.: +7 (347) 255-57-21; ORCID: https://orcid.org/0000-0002-8653-3208).

At present, providing safe working conditions and preserving workers' health are among the most challenging tasks for the state to solve. Solutions to them should be based on managing occupational risks (OR) including hazard identification, OR assessment and measures aimed at their mitigation[1].

According to the Order issued by the RF Ministry of Labor on December 28, 2021 No. 926[2], an employer can select a procedure for occupational risk assessment depending on specific production, hazards and/or harmful occupational factors existing at workplaces. As stipulated by the aforementioned Order, health risks for workers may be assessed using the procedure described in the Guide R 2.2.1766-03[3] when it comes down to personified assessment.

This procedure involves identifying harmful occupational factors, assessing OR as per hygienic and biomedical health indicators, and determining urgency of activities aimed at OR mitigation.

This procedure is especially suitable for workers who are exposed to harmful working conditions at their workplaces and who have high health risks associated with occupational diseases and work-related ones.

By now, principles and criteria of OR assessment have been tested on occupational groups of workers employed in various branches including those with high health risks at workplaces [1, 2].

Enterprises that deal with polymetallic ore mining belong to productions with high health risks for workers. A share of workplaces with working conditions that do not conform to hygienic standards varies from 30 to 65 % in this branch and workers employed at such enterprises have high risks of developing occupational or work-related diseases (OD or WRD) [3, 4].

Enterprises dealing with polymetallic ore mining employ certain common technological processes; nevertheless, there are peculiarities depending on ways to mine ores, physical and chemical properties of ores, climate and geographical conditions in places where ore deposits are located. All these peculiarities lead to differences in both working conditions and OR occurrence [5–9].

Polymetallic ore mining is associated with risks of occupational diseases of the nervous system (NS), musculoskeletal system (MSS), respiratory system and hearing organ [10, 11].

Occupational pathology of respiratory organs (chronic dust bronchitis, pneumoconiosis) depends on the mineralogical structure of ore dust, size and shape of its particles, as well as exposure levels and duration [12–14].

Apart from silicon dioxide, ore dust can contain such toxic elements as platinum, nickel, chromium, vanadium, manganese, mercury, arsenic, and uranium [15–17]. Some of these chemicals can produce genotoxic and carcinogenic effects [18–20]. Given that, several researchers have pointed out the necessity to determine several classical biomarkers such as the comet assay, micronucleus assay and chromosome aberrations [21, 22].

In addition to ore dust, workplace air can contain exhaust gases from internal combustion engines. These gases are a complex mixture of carbon oxide, nitrogen, aldehydes and sulfur dioxide [23].

---

[1] Trudovoi kodeks Rossiiskoi Federatsii ot 30.12.2001 № 197-FZ (red. ot 25.02.2022) (s izm. i dop., vstup. v silu s 01.03.2022); prinyat Gos. Dumoi 21.12.2001 [The Labor Code of the Russian Federation issued on December 30, 2001 No. 197-FZ (last edited on February 25, 2022) (with alterations and addenda that came into force on March 01, 2022); passed by the State Duma on December 21, 2001]. *KonsultantPlus*. Clauses 208, 209, 212. Available at: http://www.consultant.ru/document/cons_doc_LAW_34683/ (March 25, 2022) (in Russian).

[2] Ob utverzhdenii Rekomendatsii po vyboru metodov otsenki urovnei professional'nykh riskov i po snizheniyu urovnei takikh riskov: Prikaz Mintruda i sotszashchity RF ot 28.12.2021 № 926 [On Approval of the Recommendations on selecting procedures for assessing occupational risks and their mitigation: The Order by the RF Ministry of Labor and Social Security dated December 28, 2021 No. 926]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/728029758 (March 23, 2022) (in Russian).

[3] R 2.2.1766-03. Occupational hygiene. Guidelines on occupational risk assessment for workers' health. Organizational and methodological aspects, principles and criteria; approved by G.G. Onishchenko, the RF Chief Sanitary Inspector and the First Deputy to the RF Public Healthcare Minister on June 24, 2003. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/901902053 (March 23, 2022) (in Russian).

The most common harmful occupational factors at ore mining enterprises include, among other things, occupational noise and vibration created by technological equipment, perforators and mining machinery [24–26].

Many works by foreign and Russian researchers have concentrated on formation of occupational health risks for workers dealing with mining various polymetallic ores (sulfide, copper-nickel, copper-zinc, ferruginous quartzite, and platinum ores) and provide quite comprehensive data on the subject [27–30].

When assessing occupational risks at enterprises dealing with mining various polymetallic ores, authors most often use such indicators as a hazard category of working conditions, occupational morbidity, work-related morbidity, and mortality [2, 9, 10, 18, 26].

This research is topical since health disorders among workers employed at copper-zinc ore mining enterprises have not been given enough attention. This concerns both workers dealing with mining copper-zinc ore in general and specific occupational groups at such productions (personified risks).

Our research goal was to perform hygienic and biomedical assessment of occupational risks for workers employed at a copper-zinc ore mining enterprise and to develop a system for managing them.

Research object and techniques. Overall, six enterprises located in Bashkortostan mine and process copper and copper-zinc pyrite ores. These enterprises produce 70 % of zinc and 30 % of copper mined in the Russian Federation. We chose the largest mining enterprise in the republic as our model one for clinical and hygienic examinations. This enterprise employs conventional technologies and equipment typical for mining at similar ore deposits.

Occupational risks were assessed for the enterprise as a whole; personified occupational health risks were assessed for basic occupational groups at the enterprise made of workers dealing with open-pit and underground mining. These occupations included drilling unit operators, excavator drivers, shaft sinkers, timberers, LHD operators and USPM operators. To assess cause-effect relations between diseases and work, we created a reference group that was made of engineers and technicians with permissible working conditions at their workplaces. Their age was similar to that of workers from the main test group.

Overall assessment of working conditions was performed based on results produced by our own hygienic examinations as well as data produced by special assessment of working conditions (SAWC) performed at the examined enterprise by a specialized organization and provided by the enterprise administration.

Actual levels of exposure to harmful occupational factors were detected in conformity with the existing regulatory and methodical documents and using verified measuring devices included into the State Registry.

Our own hygienic assessment covered several harmful occupational factors identified at workplaces of workers from the selected occupational groups. They included a chemical factor (adverse chemicals); occupational noise and vibration (whole-body and local); lighting (natural or artificial); ionizing and non-ionizing radiation; exposure to predominantly fibrogenic aerosols (PFA) (silicon dioxide in copper-sulfide ore dust, silica dust (cement)); microclimate; work heaviness and intensity.

The results produced by these hygienic examinations made it possible to determine respective hazard categories of working conditions according to the provisions fixed in the Guide R 2.2.2006-05[4].

Occupational risks were assessed as per hygienic criteria and biomedical indicators in conformity with the Guide R 2.2.1766-03[3] as well as the Guide edited by N.F. Izmerov[5]. We

[4] R 2.2.2006-05. Occupational hygiene. Guide on Hygienic Assessment of Factors of Working Environment and Work Load. Criteria and Classification of Working Conditions; approved by G.G. Onishchenko, the RF Chief Sanitary Inspector on July 29, 2005; came into force on November 01, 2005. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200040973 (March 23, 2022) (in Russian).

[5] Professional'nyi risk dlya zdorov'ya rabotnikov: rukovodstvo [Occupational health risks for workers: the guide]. In: N.F. Izmerov, E.I. Denisov eds. Moscow, Trovant, 2003, 448 p. (in Russian).

considered such indicators as annual detected occupational morbidity, average annual occupational morbidity per 10,000 workers and occupational diseases index (I_{OD}) over 2011–2020, as well as work-related morbidity (relative risk (*RR*) with 95 % confidence interval (CI) and etiological fraction (EF)).

Occupational morbidity at the enterprise as a whole was compared with the data on occupational morbidity in Bashkortostan[6] and the Russian Federation[7] (RF) taken from official sources.

We determined a category of an occupational risk for each considered indicator using a five-score scale for it (negligible, moderate, average, high and extremely high). The category was estimated both for the enterprise as a whole and for specific occupational groups.

Statistical analysis was performed with IBM SPSS Statistics 21 software package (IBM, USA). Distributions were checked for normalcy using Kolmogorov – Smirnov test.

Results and discussion. Even though up-to-date equipment with great unit power was installed and all major technological processes employed at the examined enterprise were mechanized, a share of workplaces with harmful working conditions according to SAWC remained rather high and exceeded 50 %. It reached even 100 % in production divisions dealing with open-pit and underground ore mining.

We established several occupational risk factors influencing health of workers from all the occupational groups involved in underground ore mining. These factors were determined as per both SAWC results and results produced by our hygienic studies and included the following: noise generated by technological equipment, copper-zinc ore dust emitted into workplace air, adverse chemicals, unfavorable microclimate, total absence of natural light, as well as work heaviness and intensity.

When a category of working conditions was determined for activities that involve occupational contacts with PFA, copper-zinc ore dust being one of them, this required preliminary chemical analysis of mining rocks for determining a mass % of silicon dioxide in them. The analysis made it possible to select an appropriate hygienic standard, the maximum permissible average shift concentration (MPC_{as}), and the further steps in a procedure for assessing fibrogenic effects produced by aerosols on lung tissue depending on their intensity.

Thus, in case silicon dioxide accounts for 10–70 % in a rock, MPC_{as} is equal to 2 mg/m^3 and an aerosol has a more apparent fibrogenic effect. We established that a mass fraction of silicon dioxide amounted to 3.2–8.4 % in the examined ore dust; this corresponded to MPC_{as} being equal to 4 mg/m^3 and weak fibrogenic effects.

Hygienic studies revealed that dust suppression by using water, a method that has become quite popular over the last decades, provides lower ore dust contents in workplace air. Average shift concentrations of silicon dioxide did not exceed permissible levels at basic workplaces.

Timberers have to prepare a cement solution used in shotcrete sprayers that splash it on the walls inside underground tunnels to strengthen them. Due to this process, workplace

---

[6] O sostoyanii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya v Rossiiskoi Federatsii: materialy k gosudarstvennomu dokladu po Respublike Bashkortostan (2011–2020 gg.) [On sanitary-epidemiological welfare of the population in the Russian Federation: the data on Bashkortostan (2011–2020)]. *Rospotrebnadzor's Regional Office in Bashkortostan*. Available at: http://02.rospotrebnadzor.ru/documen/state_reports_on_RB/ (March 11, 2022) (in Russian).

[7] O sostoyanii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya v Rossiiskoi Federatsii: Gosudarstvennyi doklad (2011–2020 gg.) [On sanitary-epidemiological welfare of the population in the Russian Federation: The State Report (2011–2020)]. *The Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing*. Available at: https://www.rospotrebnadzor.ru/documents/documents.php?back_url_admin=%2Fbitrix%2Fadmin%2Fiblock_admin.php%3Ftype%3Ddocuments%26lang%3Dru%26admin%3DY&clear_cache=Y&arrFilter_ff%5BNAME%5D=%EE+%F1%EE%F1%F2%EE%FF%ED%E8%E8+%F1%E0%ED%E8%F2%E0%F0%ED%EE-%FD%EF%E8%E4%E5%EC%E8%EE%EB%EE%E3%E8%F7%E5%F1%EA%EE%E3%EE+%E1%EB%E0%E3%EE%EF%EE%EB%F3%F7%E8%FF&arrFilter_pf%5BVID_DOC%5D=97&arrFilter_pf%5BNUM_DOC%5D=&arrFilter_pf%5BDAT_DOC%5D=&arrFilter_pf%5BGOD%5D%5BLEFT%5D=&arrFilter_pf%5BGOD%5D%5BRIGHT%5D=&set_filter=%CD%E0%E9%F2%E8&set_filter=Y (March 11, 2022) (in Russian).

air in such zones contained silica dust (cement) aerosols with weak fibrogenic effects. When dried cement powder was poured into sprayers and then mixed with water, concentrations of silica dust were by up to 2.1 times higher than its permissible level in workplace air.

Powerful up-to-date equipment used in technological processes produced vibration and acoustic effects. Noise generated at workplaces of workers from all the examined occupational groups exceeded permissible hygienic levels for this type of activity and this concerned both open-pit and underground mining. Working conditions were considered hazardous as per exposure to noise and their hazard category varied from 3.1 to 3.3.

Microclimate in mine faces was determined by rather low air temperature (from +12 to +16 °C) and elevated humidity (80–90 %) due to dust suppression by using water.

Working conditions for workers in underground mines were characterized with absence of any natural light and therefore were considered hazardous as per this factor. Devices that compensated for ultraviolet deficiency were installed in mines and this made it possible to achieve a reduction in the hazard category at these workplaces, from 3.2 to 3.1.

Since the mined ores contained chemical admixtures with natural radiation, dosimetric control of radiation at workplaces was implemented at relevant underground locations and in production workshops. Levels of ionizing radiation did not exceed the existing hygienic standards for mining operations.

We compared hazard categories of working conditions determined as per results produced by our hygienic studies and by SAWC and revealed certain differences as per such factors as vibration and work heaviness. They did not exert any significant influence on the overall assessment (Table 1).

A hazard category as per each harmful occupational factor detected at the analyzed workplaces varied from permissible (category 2) to hazardous, from category 3.1 to category 3.4.

The results produced both by SAWC and our hygienic studies indicated that the overall assessment of working conditions at workplaces of workers from the basic occupational groups dealing with underground ore mining allowed assigning them into the hazard category 3.2–3.4, occupational risks varying from average to very high (Table 2).

Workers dealing with open-pit mining were mostly exposed to vibration and noise at their workplaces together with copper-sulfide dust, unfavorable microclimate and work heaviness. Their working conditions were assigned into hazard categories 3.2 and 3.3 with occupational risks being high at their workplaces (Tables 1 and 2).

Table 1

Key occupational factors and categories of working conditions for workers from basic occupational groups at the copper-sulfide ore mining enterprise

Occupations	Vibration	Noise	Micro-climate	PFA	Lighting	Adverse chemicals	Work heaviness	Work intensity	Result
Open-pit mining									
Drilling unit operator	2 / 2*	3.3 / 3.3	3.1 / 2	2 / 2	2 / 2	2 / 2	3.1 / 3.1	3.1 / 3.1	3.3 / 3.3
Excavator driver	2 / 3.1	3.1 / 3.1	2 / 2	2 / 2	2	2 / 2	3.1 / 3.1	3.1 / 3.1	3.2 / 3.2
Underground mining									
Shaft sinker	2 / 3.1	3.4 / 3.4	3.1 / 3.1	2 / 2	3.1 / 3.1	2 / 2	3.1 / 3.1	2 / 2	3.4 / 3.4
Drilling unit operator	2 / 2	3.3 / 3.3	3.1 / 3.1	2 / 2	3.1 / 3.1	2 / 2	2 / 3.1	2 / 2	3.3 / 3.3
Timberer	2 / 2	3.1 / 3.1	3.1 / 3.1	3.1 / 3.1	3.1 / 3.1	2 / 2	3.1 / 3.1	2 / 2	3.2 / 3.2
LHD operator	2 / 2	3.2 / 3.2	2 / 2	2 / 2	3.1 / 3.1	2 / 2	2 / 2	3.1 / 3.1	3.2 / 3.2
USPM operator	2 / 2	3.1 / 3.1	2 / 2	2 / 2	3.1 / 3.1	2 / 2	2 / 2	3.1 / 3.1	3.2 / 3.2

Note: * means working conditions category as per SAWC / working conditions category as per results of our hygienic studies.

Table 2

Personified occupational risks for basic occupations at the copper-sulfide ore mining enterprise

Indicators	Open-pit mining		Underground mining				
	Drilling unit operator	Excavator driver	Shaft sinker	Drilling unit operator	Timberer	LHD operator	USPM operator
Category of working conditions*,**	3.3	3.2	3.4	3.3	3.2	3.2	3.2
Risk category	high	average	extremely high	high	average	average	average
Average annual occupational morbidity over 10 years, ‰	98.1	134.5	333.0	108.1	47.1	22.2	14.9
Risk category	high	high	high	high	above average	above average	average
Occupational diseases index I_{OD}*,**	0.38	0.22	0.50	0.49	0.49	0.32	0.30
Risk category	high	average	extremely high	high	high	high	high
Work-related morbidity* *RR* EF, %	 3.1 66.1	 3.0 65.2	 4.3 77.8	 3.1 66.1	 2.7 65.0	 1.8 45.3	 1.9 47.5
Causation	high	high	extremely high	high	high	average	average
The resulting number of indicators with a specific risk category	4 – "high"	2 – "high", 2 – "average"	3 – "extremely high", 1 – "high"	4 – "high"	2 – "high", 1 – "above average", 1 – "average"	1 – "high", 1 – "above average", 2 – "average"	1 – "high", 3 – "average"

Note: * means the assessment accomplished as per R 2.2.1766-03[3]; **, as per the Guide edited by N.F. Izmerov[5].

Occupational morbidity is known to be a direct indicator showing how working conditions influence workers' health [10, 11]. Given that, we analyzed occupational morbidity at the enterprise as a whole and in specific occupational groups involved in open-pit and underground ore mining.

Over the period from 2011 to 2021, annual detected occupational morbidity varied from 5.6 to 29.31 cases per 10,000 workers; this meant the morbidity rate corresponded to average–high occupational risks and was by 10.0–19.0 times higher than overall morbidity in Bashkortostan and by 4.5–15.3 times higher than the morbidity in the RF as a whole. Average annual morbidity over 10 years amounted to 1.7 cases per 10,000 workers at the enterprise as a whole and corresponded to low occupational risk.

The data analysis revealed the highest occupational morbidity rates among workers dealing with ore mining. They accounted for 85.7 % of all the occupational diseases registered at the enterprise. Average annual OM among workers dealing with ore mining varied from 14.9 to 333.0 cases per 10,000 over 10 years (Table 2). We should note that these rates were by 8.8–195.9 times higher than at the enterprise as a whole.

We calculated this indicator for specific occupational groups considering actual numbers of workers in them. The results showed the highest OM rates among timberers, 333.0 cases per 10,000 workers; they were followed by excavator drivers, 134.5 cases per 10,000 workers; and drilling unit operators, 108.1 per 10,000 workers. These results confirm that the indicator is much more informative for specific occupations in comparison with the same indicator calculated for the enterprise in general.

Overall, 61 cases of occupational diseases were registered at the examined enterprise over the observation period. Diseases of the musculoskeletal system prevailed in the structure of accumulated occupational morbidity (26.9 %), the next were sensorineural hearing loss (25.0 %) and vibration disease (23.3 %). They were followed by diseases of the peripheral nervous system (17.3 %) and diseases of the respiratory organs (7.5 %).

We analyzed how cases of occupational diseases were distributed in specific occupational groups. Figure 1 provides the results.

The index I_{OD} that considered a probability of an occupational risk and severity of an occupational disease amounted to 0.33 for sensorineural hearing loss; 0.33, polyneuropathy; 0.25, vibration disease; 0.13, chronic bronchitis.

Chronic non-communicable diseases detected in workers during periodical medical examinations (PME) belonged to the following main groups: diseases of the musculoskeletal system (33 %); diseases of the nervous system (17.6 %); diseases of the circulatory organs (13.3 %); diseases of the respiratory organs (12.5 %); diseases of the ENT organs (11.3 %).

The leading role belonging to occupational factors and factors related to labor process was confirmed in workers from various occupational groups only for diseases of the musculoskeletal system (dorsopathy and arthropathy), circulatory diseases (hypertension) and respiratory diseases (chronic bronchitis). Occupational causation of these diseases varied from 1.6 to 4.3 as per a relative risk and from 42.3 to 77.8 as per etiological fraction. This means that occupational causation varied from average to extremely high (Table 3).

Frequency of other chronic non-communicable diseases in ore miners did not have any authentic differences from the same indicators in the reference group.

Shaft sinkers had the highest occupational risk rates as per all the analyzed indicators (three indicators rated "extremely high" and one indicator rated "high"); drilling unit operators followed (four indicators rated as "high"); then, timbereres (two indicators rated as "high", one as "above average" and one as "average"); excavator drivers (two indicators rates as "high and two as "average"); LHD operators (one indicator rated as "high", one as "above average" and two as 'average"); and USPM operators (one indicator rated as 'high" and three as "average").

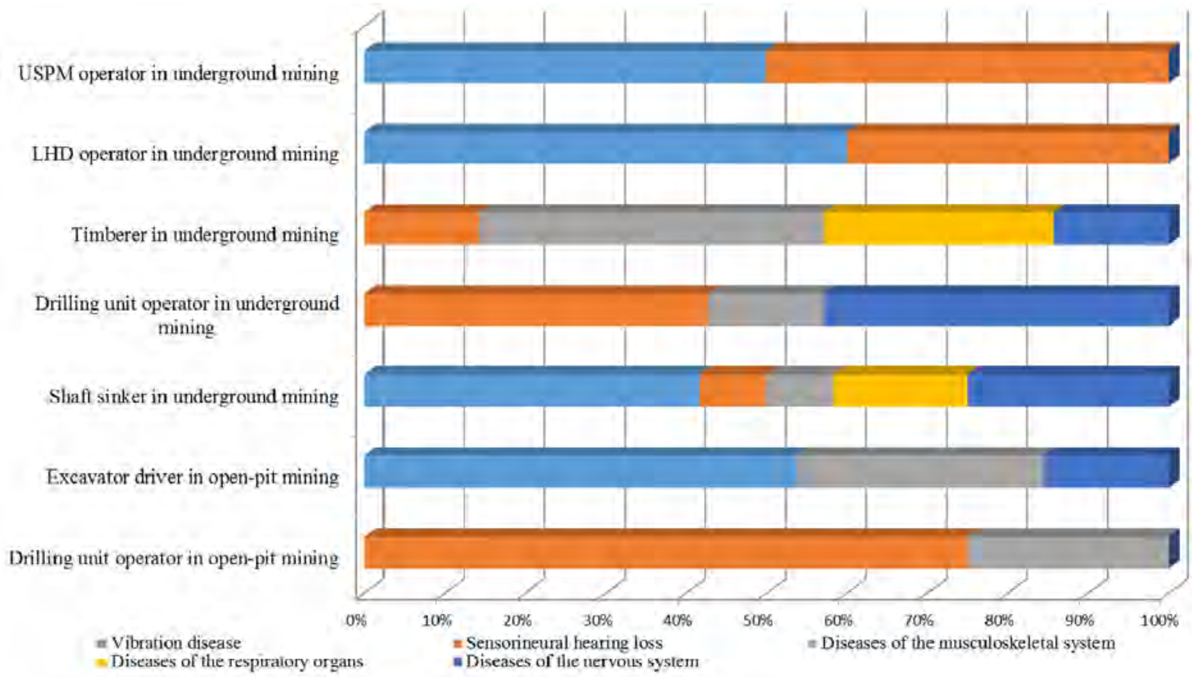

Figure 1. The structure of occupational diseases among workers form basic occupational groups at the copper-sulfide ore mining enterprise

Table 3

Occupational causation of health disorders among workers from the basic occupational groups

Mining type, occupation	Disease	*RR*	Range (95 % CI)	EF, %	Causation
1	2	3	4	5	6
Open-pit mining					
Drilling unit operator	Dorsopathy	3.1	1.6–4.7	66.0	high
	Arthropathy	3.1	1.7–4.6	66.1	high
	Chronic bronchitis	1.9	0.9–3.0	47.3	average
	Hypertension	1.8	0.7–3.0	45.3	average
Excavator driver	Dorsopathy	3.0	1.5–4.6	65.2	high
	Arthropathy	2.5	1.1–4.0	61.0	high
	Chronic bronchitis	1.6	0.5–2.7	43.3	average
	Hypertension	1.6	0.5–2.7	43.3	average
Underground mining					
Shaft sinker	Dorsopathy	4.3	3.1–5.5	77.8	extremely high
	Arthropathy	3.3	1.8–4.8	67.3	extremely high
	Chronic bronchitis	2.7	1.1–4.2	64.2	high
	Hypertension	1.8	0.7–3.0	45.3	average
Drilling unit operator	Dorsopathy	3.1	1.6–4.7	66.0	high
	Arthropathy	3.1	1.7–4.6	66.1	high
	Chronic bronchitis	1.9	0.9–3.0	47.3	average
	Hypertension	1.8	0.7–3.0	45.3	average
Timberer	Dorsopathy	2.7	1.2–4.2	65.0	high
	Arthropathy	2.6	1.1–3.9	61.5	high
	Chronic bronchitis	1.8	0.7–3.0	43.0	average
	Hypertension	1.7	0.8–3.1	42.3	average
LHD operator	Dorsopathy				
	Arthropathy	1.8	0.7–3.0	45.0	average
	Chronic bronchitis				
	Hypertension	1.8	0.7–3.0	45.3	average
USPM operator CM	Dorsopathy				
	Arthropathy	1.8	0.7–3.0	47.2	average
	Chronic bronchitis				
	Hypertension	1.9	0.9–3.0	47.5	average

Therefore, our research results made it possible to assess occupational health risks considering hygienic and biomedical indicators and to determine risk categories both for the enterprise in general and for the basic occupational groups.

We established that working conditions for workers dealing with copper-sulfide ore mining belonged to the hazard category 3.2–3.4 and occupational risks at these workplaces were average and extremely high.

Average annual occupational morbidity varied from 14.9 to 333.0 cases per 10,000 for different occupational groups over the analyzed 10 years. It was by 8.8–195.9 times higher than the same indicator taken for the enterprise as a whole. This means it is quite reasonable to determine this indicator for specific occupations. Consequently, assessment of personified occupational risks for specific occupational groups provides data that are more authentic.

Although occupational risks taken as per average annual occupational morbidity over 10 years were assessed as high (more than 50 cases) for shaft sinkers, drilling unit operators (open-pit and underground mining), and excavator drivers, numeric values of this indicators were by 2.5–22.0 times different in various occupational groups. We believe that the aforementioned criteria could become more significant if their more precise and more profound quantification was performed and their gradation was given according to relevant assessment scales described in the Guide edited by N.F. Izmerov.[5]

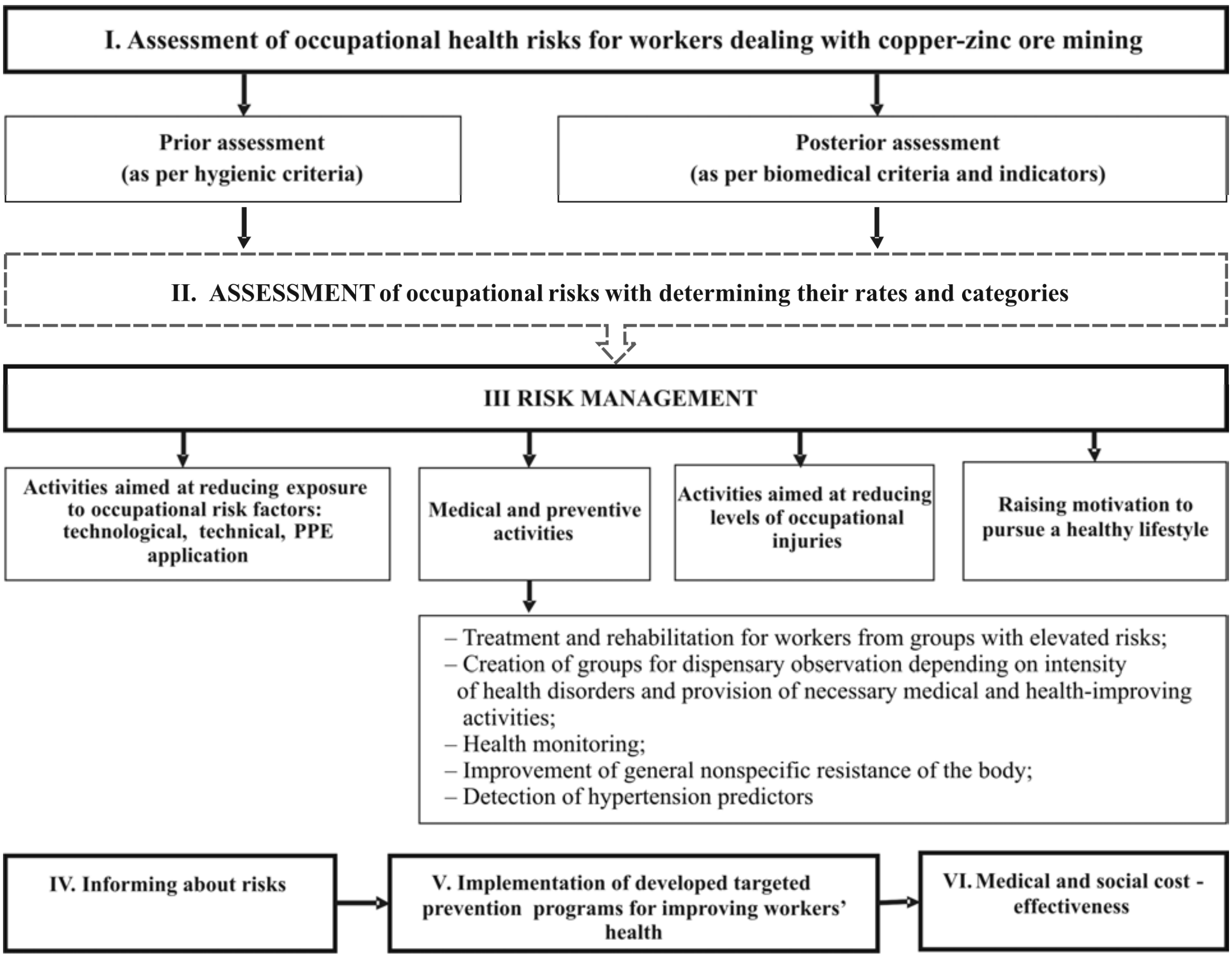

Figure 2. The system for assessing and managing occupational health risks for workers employed at copper-sulfide ore mining enterprises

We also think that occupational risk assessment requires using not only indicators that describe how many occupational diseases have been detected in the current year but also "accumulated" occupational morbidity that makes it possible to establish peculiarities in formation of its structure.

Intensity of exposure to occupational factors as well as work heaviness determines the maximum values of etiological fraction in the development of such diseases of the musculoskeletal system as dorsopathy and arthropathy.

Shaft sinkers had the highest occupational health risk as per all the analyzed indicators; they were followed by drilling unit operators, timberers, excavator drivers, LHD operators and USPM operators.

Conclusion. We have established high occupational health risks for workers from the basic occupational groups dealing with copper-zinc ore mining. These risks need to be mitigated immediately.

Given that and based on the systemic approach to health risk analysis, we have developed a system for assessing and managing occupational health risks for workers employed at copper-sulfide ore mining enterprises (Figure 2).

The system for OR management involves technical, technological, organizational, medical and preventive activities. Their urgency is to be determined as per detected categories of occupational risks.

Periodical medical examinations that include physical fitness testing, creation of groups with elevated "risks" of occupational diseases and dispensary observation are important components in prevention.

Implementation of the system will depend on effective interactions between employers, workers, and medical organizations responsible for providing medical assistance to workers employed at mining enterprises.

Funding. The research was not granted any financial support.

Competing interests. The authors declare no apparent or potential competing interests.

References

1. Chebotarev A.G., Sokur O.V. Actual issues of preservation of metallurgists' health. *Meditsina truda i promyshlennaya ekologiya*, 2019, vol. 59, no. 9, pp. 801. DOI: 10.31089/1026-9428-2019-59-9-801-802 (in Russian).

2. Chebotarev A.G., Sokur O.V., Duryagin I.N. Professional'naya zabolevaemost' i ee profilaktika na predpriyatiyakh chernoi metallurgii [Occupational morbidity and its prevention at ferrous metallurgy enterprises]. *Metallurg*, 2021, no. 12, pp. 100–103 (in Russian).

3. Syurin S.A., Kovshov A.A. Working conditions and work-related pathologies at enterprises located in Chukotka autonomous area. *Health Risk Analysis*, 2020, no. 4, pp. 99–106. DOI: 10.21668/health.risk/2020.4.11.eng

4. Chebotarev A.G., Sementsova D.D. Comprehensive assessment of working conditions and occupational disease rates at mining and metallurgical enterprises. *Gornaya promyshlennost'*, 2021, no. 1, pp. 114–119. DOI: 10.30686/1609-9192-2021-1-114-119 (in Russian).

5. Bukhtiyarov I.V., Chebotarev A.G. Gigienicheskie problemy uluchsheniya uslovii truda na gornodobyvayushchikh predpriyatiyakh [Hygienic problems of improving labor conditions at mining enterprises]. *Gornaya promyshlennost'*, 2018, no. 5 (141), pp. 33. DOI: 10.30686/1609-9192-2018-5-141-33-35 (in Russian).

6. Bukhtiyarov I.V., Chebotarev A.G., Courierov N.N., Sokur O.V. Topical issues of improving working conditions and preserving the health of workers of mining enterprises. *Meditsina truda i promyshlennaya ekologiya*, 2019, vol. 59, no. 7, pp. 424–429. DOI: 10.31089/1026-9428-2019-59-7-424-429 (in Russian).

7. Friedman L.S., Almberg K.S., Cohen R.A. Injuries associated with long working hours among employees in the US mining industry: risk factors and adverse outcomes. *Occup. Environ. Med.*, 2019, vol. 76, no. 6, pp. 389–395. DOI: 10.1136/oemed-2018-105558

8. Chebotarev A.G., Leskina L.M., Golovkova N.P. Working conditions and occupational health risks of workers in open-pit ore mines. *Gornaya promyshlennost'*, 2020, no. 5, pp. 115–119. DOI: 10.30686/1609-9192-2020-5-115-119 (in Russian).

9. Muller N.V., Mladova T.A. Assessment of the professional risk of the sinker of the drilling and blasting site. *XXI vek: itogi proshlogo i problemy nastoyashchego plyus*, 2022, vol. 11, no. 1 (57), pp. 91–95. DOI: 10.46548/21vek-2022-1157-0018 (in Russian).

10. Chebotarev A.G., Sokur O.V., Duryagin I.N. Occupational illness of employees of enterprises of mining and metals sector and ways of its reduction. *Metallurg*, 2019, no. 4, pp. 13–18 (in Russian).

11. Sokur O.V., Chebotarev A.G., Duryagin I.N. Sovremennoe sostoyanie uslovii truda i professional'noi zabolevaemosti rabotnikov predpriyatii polucheniya alyuminiya [The current state of working conditions and occupational morse rate of employees in aluminum production enterprises]. *Metallurg*, 2020, no. 2, pp. 8–12 (in Russian).

12. Chebotarev A.G. Risks of development of dust-related occupational diseases of ore mine workers. *Gornaya promyshlennost'*, 2018, vol. 139, no. 3, pp. 66. DOI: 10.30686/1609-9192-2018-3-139-66-70 (in Russian).

13. Dias da Cunha K.M., Dalia Pereira K.C., Guimarães J.R.D., Lima C., Nascimento J.E.C., Lima R., Hecht A.A., Fiel J.C.B. Study of worker's exposure to Tantalum-bearing particles in a mining and metallurgical plant. *Environ. Geochem. Health*, 2018, vol. 40, no. 5, pp. 2037–2048. DOI: 10.1007/s10653-016-9849-6

14. Gholami A., Tajik R., Atif K., Zarei A.A., Abbaspour S., Teimori-Boghsani G., Attar M. Respiratory Symptoms and Diminished Lung Functions Associated with Occupational Dust Exposure Among Iron Ore Mine Workers in Iran. *Open Respir. Med. J.*, 2020, vol. 14, pp. 1–7. DOI: 10.2174/1874306402014010001

15. Utembe W., Faustman E.M., Matatiele P., Gulumian M. Hazards identified and the need for health risk assessment in the South African mining industry. *Hum. Exp. Toxicol.*, 2015, vol. 34, no. 12, pp. 1212–1221. DOI: 10.1177/0960327115600370

16. Nemery B., Banza Lubaba Nkulu C. Assessing exposure to metals using biomonitoring: Achievements and challenges experienced through surveys in low- and middle-income countries. *Toxicol. Lett.*, 2018, vol. 298, pp. 13–18. DOI: 10.1016/j.toxlet.2018.06.004

17. Soltani N., Keshavarzi B., Moore F., Cave M., Sorooshian A., Mahmoudi M.R., Ahmadi M.R., Golshani R. In vitro bioaccessibility, phase partitioning, and health risk of potentially toxic elements in dust of an iron mining and industrial complex. *Ecotoxicol. Environ. Saf.*, 2021, vol. 212, pp. 111972. DOI: 10.1016/j.ecoenv.2021.111972

18. Serebryakov P.V., Fedina I.N., Rushkevich O.P. Features of malignant neoplasms formation in respiratory system of workers engaged into mining and processing of copper-nickel ores. *Meditsina truda i promyshlennaya ekologiya*, 2018, no. 9, pp. 9–15. DOI: 10.31089/1026-9428-2018-9-9-15 (in Russian).

19. Da Silva Júnior F.M.R., Tavella R.A., Fernandes C.L.F., Soares M.C.F., de Almeida K.A., Garcia E.M., da Silva Pinto E.A., Baisch A.L.M. Genotoxicity in Brazilian coal miners and its associated factors. *Hum. Exp. Toxicol.*, 2018, vol. 37, no. 9, pp. 891–900. DOI: 10.1177/0960327117745692

20. Da Silva Júnior F.M.R., Tavella R.A., Fernandes C.L.F., Dos Santos M. Genetic damage in coal and uranium miners. *Mutat. Res. Genet. Toxicol. Environ. Mutagen.*, 2021, vol. 866, pp. 503348. DOI: 10.1016/j.mrgentox.2021.503348

21. Sinitsky M.Yu., Minina V.I., Gafarov N.I., Asanov M.A., Larionov A.V., Ponasenko A.V., Volobaev V.P., Druzhinin V.G. Assessment of DNA damage in underground coal miners using the cytokinesis-block micronucleus assay in peripheral blood lymphocytes. *Mutagenesis*, 2016, vol. 31, no. 6, pp. 669–675. DOI: 10.1093/mutage/gew038

22. Espitia-Pérez L., da Silva J., Brango H., Espitia-Pérez P., Pastor-Sierra K., Salcedo-Arteaga S., de Souza C.T., Dias J.F. [et al.]. Genetic damage in environmentally exposed populations to open-pit coal mining residues: Analysis of buccal micronucleus cytome (BMN-cyt) assay and alkaline, Endo III and FPG high-throughput comet assay. *Mutat. Res. Genet. Toxicol. Environ. Mutagen.*, 2018, vol. 836, pt B, pp. 24–35. DOI: 10.1016/j.mrgentox.2018.06.002

23. Chebotarev A.G., Gibadulina I.Yu., Goryachev N.S. Contamination of mine air with exhaust gases of self-propelled machinery and proposed corrective measures. *Gornaya promyshlennost',* 2019, vol. 144, no. 2, pp. 74–76. DOI: 10.30686/1609-9192-2019-2-144-74-76 (in Russian).

24. Fokin V.A. Assessment of the health risk of workers in the extractive industries when exposed to noise above 80 dBA. *Meditsina truda i promyshlennaya ekologiya,* 2020, vol. 60, no. 11, pp. 867–869. DOI: 10.31089/1026-9428-2020-60-11-867-869 (in Russian).

25. Chebotarev A.G., Courierov N.N. Hygienic assessment of noise and vibration affecting workers at mining operations. *Gornaya promyshlennost'*, 2020, no. 1, pp. 148–153. DOI: 10.30686/1609-9192-2020-1-148-153 (in Russian).

26. Courierov N.N., Chebotarev A.G. Health risks for mining machine operators caused by exposure to noise and vibration. *Gornaya promyshlennost'*, 2022, no. 1, pp. 138–143. DOI: 10.30686/1609-9192-2022-1-138-143 (in Russian).

27. Nelson G., Murray J. Silicosis at autopsy in platinum mine workers. *Occup. Med. (Lond.),* 2013, vol. 63, no. 3, pp. 196–202. DOI: 10.1093/occmed/kqs211

28. Chebotarev A.G., Pfaf V.F., Gibadulina I.Yu. Current state of labour conditions, occupational morbidity and improvement of medical and preventive care for employees of mining operations. *Gornaya promyshlennost'*, 2021, no. 3, pp. 139–143. DOI: 10.30686/1609-9192-2021-3-139-143 (in Russian).

29. Melentev A.V., Serebryakov P.V. The role of physical factors of the working environment in the formation of arterial hypertension. *Meditsina truda i promyshlennaya ekologiya*, 2019, vol. 59, no. 9, pp. 692–693. DOI: 10.31089/1026-9428-2019-59-9-692-693 (in Russian).

30. Zeng X., DeBono N.L., Harris A.M., Arrandale V.H., Demers P.A. Neurodegenerative diseases among miners in Ontario, Canada, using a linked cohort. *Occup. Environ. Med.,* 2020, vol. 78, no. 6, pp. 385–392. DOI: 10.1136/oemed-2020-106958

Shaykhlislamova E.R., Karimova L.K., Beigul N.A., Muldasheva N.A., Fagamova A.Z., Shapoval I.V., Volgareva A.D., Larionova E.A. Occupational health risk for workers from basic occupational groups employed at copper and zinc ore mining enterprises: assessment and management. Health Risk Analysis, 2022, no. 2, pp. 107–118. DOI: 10.21668/health.risk/2022.2.10.eng

Received: 27.04.2022
Approved: 31.05.2022
Accepted for publication: 21.06.2022