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Review

HEALTH DISORDERS IN WORKERS ASSOCIATED WITH HEALTH RISKS AT WORKPLACES IN MINING INDUSTRY IN THE ARCTIC (ANALYTICAL REVIEW)

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The review analyzes a range and prevalence of health disorders in workers employed at mining enterprises in the Arctic and exposed to heterogeneous occupational factors. We revealed that working processes typical for basic occupations in underground mining involved exposure to a set of heterogeneous harmful and (or) hazardous occupational factors such as intense occupational noise; elevated vibration; aerosols with predominantly fibrogenic effects, dusts and chemicals; high hardness and intensity typical for physical work; non-ionizing electromagnetic radiation. It was shown that diseases of the ear and mastoid, vibration syndrome, diseases of the musculoskeletal system, respiratory diseases and diseases of the nervous system prevailed both in the structure of general morbidity and in occupational one typical for miners. To create proper working conditions and to minimize effects of harmful and hazardous occupational factors as well as occupational health risks, it is advisable to perform comprehensive hygienic assessment of introduced equipment, machinery and mechanisms; to establish levels and doses of occupational factors. Engineering and technical, technological, medical and preventive and treatment and health-improving activities should be developed on this basis with special emphasis on such occupational groups as drift miners, drill-operators, blasters, timbermen, operators of cargo handling machinery, drilling unit operators, miners in mining outputs and faces, repairmen, and electric gas welders. It seems extremely vital to apply risk assessment methodology to assess occupational health risks for workers employed in mining operations in the Norilsk industrial region considering climatic features of the Arctic. This assessment is important for substantiating relevant activities aimed at managing such risks and protecting workers' health.

Keywords: *mining industry, occupational risk factors, occupational morbidity, the Arctic.*

The Basics of the State Policy of the Russian Federation for the period up to 2035[1] outline major national interests of the country. They include providing high quality of life and wellbeing for people living in the Arctic regions in the country; development of these regions as a strategic resource base and their rational use for accelerating eco-

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[1] Ob Osnovakh gosudarstvennoi politiki Rossiiskoi Federatsii v Arktike na period do 2035 goda: Ukaz Prezidenta Rossiiskoi Federatsii ot 5 marta 2020 g. № 164 [On the Basics of the State Policy of the Russian federation in the Arctic for the period up to 2035: The RF President Order issued on March 05, 2020 No. 164]. *Prezident Rossii*. Available at: http://www.kremlin.ru/acts/bank/45255 (January 27, 2023) (in Russian); Ob utverzhdenii gosudarstvennoi programmy Rossiiskoi Federatsii «Sotsial'no-ekonomicheskoe razvitie Arkticheskoi zony Rossiiskoi Federatsii: Postanovlenie Pravitel'stva Rossiiskoi Federatsii ot 30 marta 2021 g. № 484 [On Approval of the State Program of the Russian Federation The Socioeconomic Development of the Arctic Zone in the Russian Federation: the RF Government Order issued on March 30, 2021 No. 484]. *Official Internet portal for legal information*. Available at: http://publication.pravo.gov.ru/Document/View/0001202104020037 (January 27, 2023) (in Russian).

nomic growth in Russia; environmental protection.

The Arctic zone has huge deposits of raw materials and it is impossible to provide sustainable development of the country without them. The Norilsk ore area is the most interesting for the country economy since it is the leading region in Russia as regards mining and processing of nickel, copper, silver and platinum group metals. Deposits located in the Norilsk ore area hold more than one third of silver ores, 73 % of nickel ores, 95 % of platinum group metals in Russia; two of them, namely Oktyabrskoye and Talnakhskoye do not have analogs in the world as per their stock. Average copper levels in ores vary between 1.11 and 4.54 % in 'coppery' ores and 4.06 % in 'solid' ones. On average, 41 % of all the copper, 86 % of all the nickel and 83 % of all the cobalt in the country are mined annually in the Norilsk ore area. It is also rich in silver deposits, 37.9 % of all the reserves in Russia. Almost all the country reserves of platinum group metals are also held in the Norilsk ore area, namely 15.2 thousand tons (95.6 %) [1, 2]. Such harmful factors as harsh climate in the Arctic, ambient air pollution due to emissions from metallurgical plants, and underground mining make issues of public health protection in Norilsk truly vital.

Work environment at mining enterprises creates unique working conditions; according to the International Labor Organization, they pose serious threats for workers [3]. Long-term studies have established that working conditions at mining enterprises in Siberia and the Far North involve exposures to many harmful factors. These factors determine levels and structure of work-related morbidity, occupational morbidity included; they are high levels of dusts, noise, local and general vibration, toxic gases and predominantly fibrogenic aerosols in workplace air, elevated exposure to chemicals in workplace air, non-ionizing radiation as well as work hardness [4, 5].

Profound analysis accomplished at mining enterprises allows stating that occupational morbidity is the highest among underground miners and is 3–4 times higher than that among workers employed in open-pit mining. Results obtained by special assessment of working conditions are widely used in practice to assess prior occupational risks caused on workers' bodies by exposure to harmful occupational factors. Some studies reported that overall assessment of working conditions performed in major occupational groups in mining established combined exposure to harmful occupational factors and therefore working conditions were considered hazardous (class 3) and assigned into hazard categories 3.2–3.4 (from average to very high hazard levels). Basic mining occupations with such hazardous working conditions at workplaces include drift miners, drill-operators, blasters, timbermen, operators of cargo handling machinery, drilling unit operators, miners in mining outputs and faces, and repairmen [6, 7]. High occupational health risks for miners are evidenced by high levels of morbidity with temporary loss of working ability. High general morbidity was identified in underground miners (drift miners, drilling unit operators and electric locomotive operators) due to diseases of the musculoskeletal system (arthrosis, diseases of muscles and soft tissues, dorsopathy), diseases of the nervous system (extremity polyneuropathy) and diseases of the ear (sensorineural hearing loss) [8].

The most common diseases with temporary loss of working ability in miners dealing with non-ferrous ore mining are diseases of the musculoskeletal system (spinal osteochondrosis, lumbodynia, arthralgia, and deforming osteoarthrosis), diseases of the digestive system (gastroduodenitis, stomach and duodenum ulcer, diseases of pancreas); diseases of the circulatory system (essential hypertension, varicose veins of lower extremities); diseases of the respiratory system (acute and chronic bronchitis); diseases of the ear and peripheral nervous system (polyneuropathy) [9, 10].

The most widely spread occupational pathologies of miners, similar to general ones, include diseases of the ear and mastoid (sensorineural hearing loss), vibration disease,

diseases of the musculoskeletal system (radiculopathy, scapulohumeral periarthritis and deforming osteoarthrosis), respiratory diseases (chronic bronchitis, bronchial asthma and chronic obstructive pulmonary disease), as well as diseases of the nervous system (vegetative-sensory polyneuropathy) [9].

Long-term physiological, hygienic, clinical and functional studies with their focus on specific working conditions in mining indicate that long-term and intensive exposure to noise as well as noise and vibration in general are priority occupational health risk factors for miners. According to some authors, intensity of exposure to occupational noise corresponds to the hazard category 3.3 (harmful working conditions, hazard category 3) for drift miners in the Norilsk ore area [11]. Exposure to noise and vibration tends to grow as new equipment is implemented due to its forced speed, power and load parameters and as the existing technological processes are intensified. Elevated noise levels are detected due to operating scraper winches and loaders[2]. In general, noise holds the leading place among all the occupational factors as regards violations of the existing hygienic standards[3] and produces harmful effects on all the organs and systems in the body, first of all, on the ear. Therefore, occupational sensorineural hearing loss is an outstanding challenge for occupational medicine [12]. Prevention of occupational sensorineural hearing loss has high medical and social significance since hearing disorders develop in people of working age and lead to loss of occupational activity and poorer quality of life. Vibration pathologies and sensorineural hearing loss under exposure to noise occupy leading places in occupational morbidity of miners. This is largely due to characteristics of occupational noise, which is higher than hygienic standards predominantly in medium and high frequency range and produces the most aggressive effects on the ear [5].

Occupational diseases of the ear are diagnosed based on several indicators including lower speech intelligibility, noise in ears, headaches, heartaches, increased fatigability, and overall weakness.

Some authors reported several mandatory indicators for establishing a relationship between the disease and an occupation. They were two-sided lesion of the ear; gradual and slow progress of the disease in case hearing was normal at the recruitment; application for medical aid due to a disease of the ear; exposure to occupational noise exceeding its permissible levels; not less than 10 years of work under exposure to occupational noise [13]. Some studies revealed that average work records equaled 21.9 ± 1.8 years for underground drift miners and 23.8 ± 1.4 years for underground drilling unit operators by the moment sensorineural hearing loss was diagnosed in them[2].

Diseases of the circulatory system are a significant health outcome of exposure to noise that does not concern hearing[4]. Still, it is noteworthy that over the last decade occupational risk factors have been assigned a major role in progression of circulatory diseases along with genetic, somatic, behavioral and environmental ones. Harmful occupational factors make a substantial contribution to progression of cardiovascular pathologies. Health disorders that describe how essential hypertension develops in workers exposed to noise higher than its permissible levels are

[2] Preobrazhenskaya E.A. Sistema upravleniya riskom razvitiya professional'noi tugoukhosti u rabotnikov gornodobyvayushchei i mashinostroitel'noi promyshlennosti [The system for managing risks of occupational sensorineural hearing loss in miners and workers employed in civil engineering]: the abstract of the thesis … for the Doctor of Medical Sciences degree. Moscow, 2013, 48 p. (in Russian).

[3] O sostoyanii sanitarno-epidemiologicheskogo blagopoluchiya naseleniya v RF v 2021 g.: Gosudarstvennyi doklad [On sanitary-epidemiological welfare of the population in the Russian Federation in 2021: The State Report]. Moscow, the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 2022, 340 p. (in Russian).

[4] Professional'naya patologiya: natsional'noe rukovodstvo [Occupational pathology: the national guide]. In: N.F. Izmerov ed. Moscow, GEOTAR-Media, 2011, 784 p. (in Russian).

considered work-related ones based on identified cause-effect relations between them and workplace exposures[5] [14, 15].

However, health disorders caused by exposure to noise levels higher than 70 dB can have such early signs as dysfunctions of the autonomic nervous system [16–18]. Several studies reported that workers who were exposed to high noise levels for a long time tended to have higher systolic and / or diastolic blood pressure than those who were not exposed to them [12, 19, 20]. According to Russian and foreign researchers, underground miners who had been working for not less than 10 years under long-term exposure to noise had not only sensorineural hearing loss but also essential hypertension and developing hypertensive disease together with background metabolic syndrome and already existing disorders of the autonomic nervous system that aggravated it [21–23]. At the same time, we can observe a close circle of pathological cause-effect reactions of the body as depletion of adaptation mechanisms and functional disorders of the circulatory system are, on one hand, outcomes of non-specific effects produced on the body by noise but on the other hand they facilitate progression of occupational sensorineural hearing loss[6].

Workers employed in mining and metallurgy tend to be exposed to high occupational vibration at workplaces [8, 24]. We should emphasize that mining usually makes workers to be simultaneously exposed to noise and vibration combined with harsh climatic conditions and these exposures exceed their permissible levels. For example, drift miners are exposed to intense local vibration (4–12 dB higher than its maximum permissible level, it means the working conditions are harmful, the hazard category is 3.3); drillers are exposed to overall vibration with its levels 3–12 dB higher than MPL, the hazard category of these working conditions is 3.2[6]. Besides, vibration and work hardness facilitate development of sensorineural hearing loss with almost the same likelihood (risk) due to impaired cerebral hemodynamics [25]. Therefore, scientific research has provided solid evidence that pathologies caused by exposure to vibration are leading ones in workers employed in contemporary mining [26, 27].

Polyneuropathy of lower extremities, radiculopathy of the lumbosacral spine, and dystrophic changes in the musculoskeletal system account for approximately one third (27.4 % of cases) of occupational diseases in all workers with diseases caused by exposure to vibration diagnosed for the first time in them [5]. Vibration pathology caused by exposure to overall vibration is most often diagnosed in operators of various mining machinery and drilling unit operators. Drift miners and face miners were occupations with the maximum risk of developing vibration pathology due to exposure to local vibration.

Vertebrogenic pathology is an interesting research subject for diagnosing and estimating associations between a disease and an occupation since radiculopathies prevail in people exposed to overall vibration; mono- or polyneuropathy and vegetative-sensory polyneuropathy seem to occur less frequently [4, 27]. Abroad, this pathology is considered a work-related one occurring due to many various causes, the contribution made by occupational factors being equal to 37 %. According to Russian researchers, radiculopathy predominantly develops in people who have static or dynamic loads on the spine, work in a forced posture, and are exposed to vibration at their workplaces. Vegetative-sensory polyneuropa-

[5] Shlyapnikov D.M. Gigienicheskaya otsenka riska razvitiya arterial'noi gipertenzii i effekta profilakticheskikh mer po ego minimizatsii u rabotnikov predpriyatii po dobyche kaliinykh solei v usloviyakh podzemnykh rabot [Hygienic assessment of a risk of essential hypertension and effects produced by preventive activities aimed at its minimization in workers employed at underground potassium salt mining]: the abstract of the thesis … for the Candidate of Medical Sciences degree. Perm, 2016, 24 p. (in Russian).

[6] Preobrazhenskaya E.A. Sistema upravleniya riskom razvitiya professional'noi tugoukhosti u rabotnikov gornodobyvayushchei i mashinostroitel'noi promyshlennosti [The system for managing risks of occupational sensorineural hearing loss in miners and workers employed in civil engineering]: the abstract of the thesis … for the Doctor of Medical Sciences degree. Moscow, 2013, 48 p. (in Russian).

thy becomes the most significant health disorder among vibration pathologies under exposure to local vibration; such exposure creates a higher risk of occupational pathology than exposure to overall vibration [4, 27]. Still, experts in occupational medicine pay more and more attention to combined exposure to several harmful occupational factors as a cause for developing neural-orthopedic pathology[7].

Work hardness is a feature of a work process associated with predominant loads on the musculoskeletal system and other functional systems in the body (cardiovascular, respiratory, etc.). It produces negative effects when combined with other occupational risk factors (noise, vibration, and some others). Work hardness is estimated as per several indicators given in ergometric values describing a work process regardless of individual features of a person who participates in it. Several well-known indicators of work hardness include physical dynamic load; a weight of a cargo a person has to lift and move manually; stereotypic work motions; static load; a work posture; body bending; the necessity to move around. In addition, work processes employed at mining enterprises involve apparent work hardness caused not only by the aforementioned factors but also high speed of work and emotional loads (a risk for one's life and responsibility for other people's lives). All basic work operations in a mine face in ore mines, even in machine mining, should be considered hard due to an uncomfortable work posture and the necessity to keep moving all the time. Excessive physical loads and frequent forced and irrational work postures lead to overstrain of the musculoskeletal system in drift miners and drill-operators [28].

Several technological processes employed in contemporary mining are still associated with work in forced and uncomfortable postures, stereotypic motions and local muscle strain. The total energy costs (145–320 kcal/hour) correspond to average and hard physical load. Working conditions at workplaces of most miners belong to the hazard category 3.1 as per work hardness [29]. The significant total amount of time a miner has to spend in an uncomfortable work posture is a factor causing overstrains in the cervical-thoracic and lumbosacral spine and occupational diseases (lumbosacral radiculopathy, plexitis, and myofascitis) [28]. Vegetative-sensory polyneuropathy of upper extremities is another significant occupational pathology developing due to exposure to such harmful occupational factors as local muscle loads, including those with switching between different work postures, and static loads.

Elevated levels of industrial aerosols are also important occupational factors occurring at workplaces in mining. Pathology caused by exposure to industrial aerosols stably accounts for approximately one third (29.3 %) of occupational diseases in Russia (B.T. Velichkovskiy, 2004). Thus, huge amounts of dusts are emitted into workplace air during drilling and blasting operations, in underground and open-pit mining, during loading and transportation of ores, their crushing and grinding, and during welding. Dusts in high concentrations can produce fibrogenic, toxic, irritating, allergenic, or carcinogenic effects depending on their chemical composition. Some industrial dusts induce occupational lung fibrosis or pneumoconiosis as well as dust bronchitis. These types of dusts are assigned into a specific group called 'aerosols with predominantly fibrogenic effects' (APFE).

Nickel and its compounds are known to produce harmful allergenic, toxic and carcinogenic effects on the lungs [30–33]. Fine dusts occurring in workplace air at copper and nickel production are highly toxic since they consist of micro- and nanoparticles with high permeability [31]. Use of diesel driverless mechanisms creates elevated levels of toxic gaseous components in their exhausts, such as nitrogen oxide, carbon oxides, acrolein, formaldehyde, and hydrocarbons. Their average

[7] Suvorov V.G. Mediko-biologicheskie osnovy otsenki sochetannogo vliyaniya faktorov proizvodstvennoi sredy i trudovogo protsessa na organizm cheloveka [Biomedical grounds for assessment of combined effects produced by occupational factors on the human body]: the abstract of the thesis … for the Doctor of Medical Sciences degree. Moscow, 2004, 48 p. (in Russian).

shift levels do not usually exceed the relevant hygienic standards but maximum ones are 5.5 times higher than MPC for nitrogen oxides and 1.5 – 2.0 times higher for carbon oxide.

Occupational pathology among miners in the Far North is characterized with high prevalence of such respiratory diseases as pneumoconiosis, acute and chronic dust bronchitis; their highest shares of the total occupational diseases are the most frequently detected in underground miners [34, 35]. Clinical and functional examinations and analysis of occupational pathologies among miners have made it possible to conclude that not only there has been a growth in occupational bronchopulmonary diseases in them but also an increase in the number of severe or complicated forms of pneumoconiosis. Besides, workplace air in mines contains toxic dusts affecting the respiratory system and exposure to them leads to asthmatic bronchitis. Studies accomplished by Russian researchers are also confirmed by data reported by foreign authors examining, for example, occupational diseases in underground miners caused by exposure to dusts. Some studies showed that pneumoconiosis was widespread among miners in America, China, and South Africa [36–38]. Some authors mentioned that calculation of occupational health risks for miners caused by exposure to dusts revealed the highest levels of such risks for mine drifters and the lowest ones for repairmen [39].

Along with the aforementioned data, clinical, functional and sanitary-chemical laboratory tests provide evidence that occupational damage to the lungs occurs in welders after 10 years of work [40]. Some up-to-date chemical and physical studies report welding aerosols to have a complex composition that depends on a welding technology, materials and mode. Basically, they contain metals and their oxides (iron, manganese, chromium, nickel, aluminum, wolfram, etc.), gaseous fluorides, as well as silicon, carbon and nitrogen oxides [41]. Welding aerosols produce fibrogenic, toxic, irritating and sensitizing effects. Diseases of the eye are pathology typical for welders. Prophylaxis aimed at preventing diseases of the eye among welders is quite effective and relevant morbidity is lower than prevalence of respiratory diseases. Welders tend to have pneumoconiosis, chronic dust bronchitis and bronchial asthma. Inhalation exposure to welding aerosols and dusts plays the most significant role in pathogenesis of these diseases [40, 42]. Still, some Russian researchers reported that cataract was among few specific health outcomes caused by exposure to non-ionizing electromagnetic radiation typical for welding. This might lead to temporary, particle or even complete vision loss. The vascular system of the eye has a very specific structure and therefore changes in this organ often occur earlier than in other organs or system. The study [39] established a direct authentic correlation between deviations in the eye health and changes in the nervous and cardiovascular systems, which are the most susceptible to occupational exposures. Cataract develops due to intensive thermal exposure on the eye created by infrared waves; they account for 30–70 % of the total energy radiated by a welding arc. Under this exposure, the crystalline lens is heated to temperatures well beyond the physiological range. The ultraviolet part of the spectrum is also significant since ultraviolet radiation causes inflammatory changes in the front structures of the eye, or such diseases as electric ophthalmia and conjunctivitis [43–45].

Therefore, our analysis of foreign and Russian studies identified potential health hazards and risks for miners and established the following. Most underground miners are exposed to a combination of harmful occupational factors and working conditions at their workplaces are estimated as harmful (class 3), hazard category 3.1–3.4; that is, hazards (harmfulness) vary between average and very high.

We have established that working processes employed at workplaces of basic occupations in underground mining involve exposure to diverse harmful and (or) hazardous occupational factors including intense occupational noise; elevated levels of overall and local vibration; inhalation exposure to aerosols with predominantly fibrogenic effects,

dusts, and chemicals; high work hardness and intensity; non-ionizing electromagnetic radiation. Occupational morbidity of underground miners employed at ore mines typically has high levels of diseases of the musculoskeletal, respiratory, and peripheral nervous system as well as circulatory diseases and diseases of the ear in its structure. To create proper working conditions and to minimize effects of harmful and hazardous occupational factors as well as occupational health risks, it is advisable to perform comprehensive hygienic assessment of introduced equipment, machinery and mechanisms; to establish safe levels and doses of occupational factors for underground miners. Engineering and technical, technological, medical and preventive measures as well as treatment and health-improving activities should be developed on this basis with special emphasis on such occupational groups as drift miners, drill-operators, blasters, timbermen, operators of cargo handling machinery, drilling unit operators, miners in mining outputs and faces, repairmen, and electric gas welders. It seems extremely vital to apply risk assessment methodology to assess occupational health risks for workers employed in mining operations in the Norilsk industrial region considering climatic features of the Arctic. This assessment is important for substantiating relevant activities aimed at managing such risks and protecting workers' health.

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