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INTERNATIONAL APPROACHES TO OCCUPATIONAL RISK MANAGEMENT AND OCCUPATIONAL HEALTH PROTECTION IN THE MINING INDUSTRY

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The mining industry is characterized by a high level of occupational risks associated with the combined effects of physical, chemical, ergonomic, and psychosocial workplace factors. This determines the relevance of analyzing international approaches to occupational risk management and the protection of workers' health.

Objective - to conduct an analytical review of international regulatory documents and scientific studies on occupational risk management and occupational health protection in the mining industry, compare current approaches to risk assessment and occupational health surveillance, and assess the applicability of these approaches in the Republic of Kazakhstan.

The study was conducted as an analytical review. The information base included regulatory and methodological documents of the International Labour Organization, World Health Organization, International Organization for Standardization, and International Commission on Occupational Health, as well as scientific publications indexed in the Scopus, Web of Science, PubMed, and ScienceDirect databases. Comparative analysis, systematization, and analytical synthesis of scientific evidence were applied.

The analysis of international documents demonstrated the formation of a complementary, multilevel framework for occupational risk management. Documents of the International Labour Organization establish the regulatory basis for occupational safety, the International Organization for Standardization 45001 standard defines principles of risk-based management, while international recommendations in occupational health and medicine provide a basis for the prevention of occupational diseases and occupational health surveillance. Scientific evidence highlights the importance of considering the combined effects of dust, noise, vibration, and other workplace hazards in the mining industry.

The application of international approaches in the Republic of Kazakhstan should focus on developing risk-based occupational risk assessment systems, strengthening occupational health services, and improving preventive health surveillance. Comprehensive epidemiological studies are needed to evaluate the effectiveness of international approaches under the conditions of Kazakhstan.

Keywords: international standards, occupational safety, occupational health, occupational risks, mining industry, health surveillance, prevention of occupational diseases.

МЕЖДУНАРОДНЫЕ ПОДХОДЫ К УПРАВЛЕНИЮ ПРОФЕССИОНАЛЬНЫМИ РИСКАМИ И ОХРАНЕ ЗДОРОВЬЯ РАБОТНИКОВ В ГОРНОДОБЫВАЮЩЕЙ ПРОМЫШЛЕННОСТИ

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Горнодобывающая промышленность относится к отраслям с высоким уровнем профессиональных рисков, обусловленных сочетанным воздействием физических, химических, эргономических и психосоциальных факторов производственной среды. Это определяет актуальность анализа международных подходов к управлению профессиональными рисками и охране здоровья работников.

Цель исследования - провести аналитический обзор международных нормативных документов и научных исследований в области управления профессиональными рисками и охраны профессионального здоровья работников горнодобывающей отрасли, сопоставить современные подходы к оценке рисков и медицинскому наблюдению, а также оценить возможности их применения в условиях Республики Казахстан.

Исследование выполнено в форме аналитического обзора. Информационную базу составили нормативные и методические документы Международной организации труда, Всемирной организации здравоохранения, Международной организации по стандартизации и Международной комиссии по гигиене труда, а также научные публикации, представленные в базах данных Scopus, Web of Science, PubMed и ScienceDirect. Использованы методы сравнительного анализа, систематизации и аналитического обобщения научных данных.

Анализ международных документов показал формирование взаимодополняющей многоуровневой системы управления профессиональными рисками. Документы Международной организации труда определяют нормативную основу обеспечения безопасности труда, стандарт Международной организации по стандартизации 45001 устанавливает принципы риск-ориентированного управления, а международные рекомендации в области здравоохранения и медицины труда формируют основу профилактики профессиональных заболеваний и медицинского наблюдения. Научные исследования свидетельствуют о необходимости учета сочетанного воздействия пыли, шума, вибрации и других производственных факторов в горнодобывающей отрасли.

Применение международных подходов в Республике Казахстан должно быть направлено на развитие риск-ориентированной системы оценки профессиональных рисков, совершенствование служб медицины труда и усиление профилактического медицинского наблюдения. Для оценки эффективности международных подходов в условиях Казахстана необходимы комплексные эпидемиологические исследования.

Ключевые слова: международные стандарты, охрана труда, медицина труда, профессиональные риски, горнодобывающая промышленность, медицинское наблюдение, профилактика профессиональных заболеваний.

ТАУ-КЕН ӨНЕРКӘСІБІНДЕ КӘСІПТІК ТӘУЕКЕЛДЕРДІ БАСҚАРУ ЖӘНЕ ҚЫЗМЕТКЕРЛЕРДІҢ ДЕНСАУЛЫҒЫН ҚОРҒАУДЫҢ ХАЛЫҚАРАЛЫҚ ТӘСІЛДЕРІ

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Тау-кен өнеркәсібі өндірістік ортаның физикалық, химиялық, эргономикалық және психоәлеуметтік факторларының бірлескен әсеріне байланысты кәсіби тәуекел деңгейі жоғары салалардың бірі болып табылады. Бұл жағдай кәсіби тәуекелдерді басқарудың және жұмыскерлердің кәсіби денсаулығын қорғаудың халықаралық тәсілдерін талдаудың өзектілігін айқындайды.

Зерттеудің мақсаты - тау-кен өнеркәсібі жұмыскерлерінің кәсіби тәуекелдерін басқару және кәсіби денсаулығын қорғау саласындағы халықаралық нормативтік құжаттар мен ғылыми зерттеулерге аналитикалық шолу жүргізу, тәуекелдерді бағалау мен медициналық бақылаудың заманауи тәсілдерін салыстыру және оларды Қазақстан Республикасының жағдайында қолдану мүмкіндіктерін бағалау.

Зерттеу аналитикалық шолу түрінде жүргізілді. Ақпараттық базаға Халықаралық еңбек ұйымының, Дүниежүзілік денсаулық сақтау ұйымының, Халықаралық стандарттау ұйымының және Халықаралық еңбек гигиенасы комиссиясының нормативтік және әдістемелік құжаттары, сондай-ақ Scopus, Web of Science, PubMed және ScienceDirect дерекқорларында жарияланған ғылыми еңбектер енгізілді. Зерттеуде салыстырмалы талдау, жүйелеу және ғылыми деректерді аналитикалық жинақтау әдістері қолданылды.

Халықаралық құжаттарды талдау кәсіби тәуекелдерді басқарудың өзара толықтыратын көпдеңгейлі жүйесі қалыптасқанын көрсетті. Халықаралық еңбек ұйымының құжаттары еңбек қауіпсіздігінің нормативтік негізін, Халықаралық стандарттау ұйымының 45001 стандарты тәуекелге бағдарланған басқару қағидаттарын, ал халықаралық денсаулық сақтау және еңбек медицинасы жөніндегі ұсынымдар кәсіби

аурулардың профилактикасы мен медициналық бақылаудың негіздерін айқындайды. Ғылыми зерттеулер тау-кен өндірісіндегі шаң, шу, діріл және басқа да өндірістік факторлардың жиынтық әсерін ескерудің маңыздылығын көрсетеді.

Қазақстан Республикасында халықаралық тәсілдерді қолдану кәсіби тәуекелдерді бағалаудың тәуекелге бағдарланған жүйесін дамытуға, еңбек медицинасы қызметтерін жетілдіруге және профилактикалық медициналық бақылауды күшейтуге бағытталуы тиіс. Қазақстан жағдайындағы халықаралық тәсілдердің тиімділігін бағалау үшін кешенді эпидемиологиялық зерттеулер жүргізу қажет.

Түйін сөздер: халықаралық стандарттар, еңбек қауіпсіздігі, еңбек медицинасы, кәсіби тәуекелдер, тау-кен өнеркәсібі, медициналық бақылау, кәсіптік аурулар профилактикасы.

Introduction. The mining industry is one of the economic sectors characterized by a high level of occupational risk due to the simultaneous exposure of workers to multiple hazardous and harmful workplace factors. Workplaces may involve concurrent exposure to industrial dust, noise, vibration, chemical substances, high or low temperatures, physical workloads, as well as technological accidents and hazardous production processes. The individual or combined effects of these factors may result in occupational injuries, the development of occupational diseases, and long-term adverse health outcomes [1-3]. Current research indicates that the health status of mine workers cannot be adequately explained by exposure to a single factor alone. For example, a comprehensive analysis of occupational risk factors in the mining industry examined the interrelationships among physical, chemical, ergonomic, and psychosocial exposures [3].

The specific characteristics of mining operations require occupational risk management to extend beyond monitoring the permissible levels of individual hazardous factors. The current approach includes systematic hazard identification, risk assessment, elimination or control of hazards at the source, selection of preventive measures, and continuous evaluation of their effectiveness. The International Labour Organization's Safety and Health in Mines Convention, 1995 (No. 176), establishes requirements based on employers' assessment of risks and the prioritization of measures aimed at eliminating or minimizing them. The Convention also provides for regular health surveillance of workers exposed to occupational hazards [4]. The International Labour Organization's 2018 code of practice on safety and health in opencast mines further develops these principles by addressing risk assessment, the safety of production processes, and the use of new technologies [5-6].

Occupational safety and health management system standards also play an important role in the international occupational risk management framework. ISO 45001:2018 establishes requirements and guidance for organizations to develop an occupational health and safety management system, eliminate hazards, and reduce occupational risks. Its key principles include the management of risks and opportunities, leadership commitment, worker participation, and continual improvement of the management system [7]. At the same time, the existence of the standard itself does not necessarily imply a reduction in occupational injuries or occupational disease incidence; its practical effectiveness depends on the quality of implementation, the organization's safety culture, and specific workplace conditions.

An important component of occupational health protection, alongside the control of workplace exposures, is the systematic medical surveillance of workers' health. International Labour Organization instruments concerning occupational health services focus on the prevention of occupational hazards, health surveillance in relation to working conditions, and the organization of preventive measures [8]. Medical surveillance enables the early detection of health changes associated with occupational exposures; however, its effectiveness is greater when it is implemented together with engineering and organizational measures aimed at reducing hazards at their source.

Research in the mining industry indicates that exposure to industrial dust, particularly mineral and respirable dust, poses a significant risk to occupational health. Review studies on exposure to mineral dust have examined its association with respiratory diseases, including pneumoconiosis and other chronic pathologies [9]. At the same time, current scientific literature emphasizes the need to consider not only dust exposure but also noise, vibration, thermal stress, chemical factors, and psychosocial exposures when assessing occupational risks. A study analyzing 259 publications on factors affecting the health of mine workers demonstrated the diversity of chemical, physical, ergonomic, and psychosocial factors associated with occupational health outcomes [3].

Accordingly, international practice has increasingly approached occupational risk management as an

integrated system in which occupational safety, industrial hygiene, medical surveillance, and worker participation are interrelated. Such an approach makes it possible to consider not only individual hazards but also their combined effects, workers' actual exposure levels, and resulting health outcomes [9]. However, the requirements of international regulatory documents and findings from current scientific studies are not always considered as an integrated analytical framework in the context of the mining industry.

For the Republic of Kazakhstan, the importance of this issue is associated with the significant role of the mining industry in the national economy and the high level of hazards inherent in its production processes. Therefore, it is necessary not only to compare international regulatory requirements with the national occupational safety system but also to determine their practical applicability to occupational risk assessment, medical surveillance, and the organization of preventive measures at mining enterprises. In this context, it is important not to directly transfer international approaches to Kazakhstan but to assess their compatibility with the country's legal, industrial, and institutional conditions.

The scientific problem addressed in this study is associated with the fact that international occupational safety standards and current scientific studies on occupational risks in the mining industry have developed along different lines, while comprehensive analysis of their interrelationships and applicability under the conditions of the Republic of Kazakhstan remains limited.

The novelty of this study lies in the integrated analysis of international occupational safety standards, scientific evidence on occupational risks, and approaches to occupational health protection in the mining industry, with particular attention to their applicability to the conditions of the Republic of Kazakhstan.

The aim of this study is to conduct an analytical review of international regulatory documents and scientific studies on occupational risk management and occupational health protection among mining workers, compare current approaches to occupational risk assessment and medical surveillance, and evaluate their applicability in the mining industry of the Republic of Kazakhstan.

Materials and Methods. The study was conducted as an analytical review. The information base included official documents of the International Labour Organization (ILO), World Health Organization (WHO), International Organization for Standardization (ISO), International Commission on Occupational Health (ICOH), and the National Institute for Occupational Safety and Health (NIOSH, USA), as well as scientific publications indexed in the Scopus, Web of Science, PubMed, and ScienceDirect databases. The literature search covered the period from 2015 to 2026.

The search strategy used the following keywords and their combinations: occupational safety, occupational health, mining industry, mine safety, occupational risk, risk management, occupational health surveillance, medical screening, mining workers, occupational dust exposure, pneumoconiosis, silica exposure, noise-induced hearing loss, vibration-related disorders, as well as ISO 45001 and ILO Convention No. 176.

The review included peer-reviewed scientific publications addressing occupational safety, occupational risks, the effects of workplace factors on workers' health, prevention of occupational diseases, and medical surveillance in the mining industry. Publications that were not relevant to the research topic, duplicates, and sources whose bibliographic information could not be fully verified were excluded. Selected earlier publications were also included to describe fundamental scientific principles related to the development of occupational diseases in the mining industry.

The selection process consisted of screening titles and abstracts, followed by an assessment of the full texts for their relevance to the objectives of the study. The selected sources were systematically classified according to the authors, year of publication, study subject, methods used, and principal findings. International regulatory documents were compared with regard to requirements for occupational risk assessment, preventive measures, medical surveillance, and occupational safety and health management.

The findings were synthesized using qualitative analytical synthesis and comparative analysis. Since the study was not designed as a meta-analysis, no quantitative statistical pooling was performed. The results were analyzed across the following areas: international regulatory frameworks, exposure to industrial dust, noise and vibration, comprehensive occupational risk assessment, medical surveillance, and the applicability of international practices to the conditions of the Republic of Kazakhstan.

Results and Discussion. The analysis showed that the international system for regulating occupational safety and occupational health in the mining industry comprises several interconnected levels. Its

regulatory foundation is formed by the conventions and recommendations of the International Labour Organization (ILO), its management framework is provided by ISO 45001:2018, while the occupational health and medical prevention component is supported by recommendations of the World Health Organization (WHO) and the International Commission on Occupational Health (ICOH) [1-6].

The ILO Safety and Health in Mines Convention, 1995 (No. 176) is the principal international legal instrument for ensuring occupational safety in mining enterprises. The Convention provides for occupational risk assessment, implementation of preventive measures, worker training, provision of personal protective equipment, and health surveillance [1]. The Safety and Health in Mines Recommendation, 1995 (No. 183) complements the Convention by specifying practical approaches for implementing its provisions at the workplace level [2].

Safety issues in opencast mining are further addressed in the ILO *Safety and Health in Opencast Mines* code of practice. The document focuses on the safe use of mining equipment and transport, prevention of emergency situations, and control of exposure to workplace factors such as dust, noise, and vibration [3].

ISO 45001:2018 establishes the management level of the international regulatory framework. Its key feature is the integration of systematic hazard identification, occupational risk assessment, worker participation in management processes, management responsibility, and the principle of continual improvement of the occupational health and safety management system [4].

WHO and ICOH documents complement this framework with mechanisms for the medical protection of occupational health. Their recommendations address health surveillance, early detection of occupational diseases, assessment of workers' fitness for work, and rehabilitation [5, 6].

A comparative characterization of the main international documents is presented in Table 1.

Table 1 - Comparative characteristics of international documents in the field of occupational safety and occupational health in the mining industry

Document	Year	Main purpose	Key requirements	Significance for the mining industry
ILO Safety and Health in Mines Convention, 1995 (No. 176)	1995	Establish mandatory international requirements	Occupational risk management, employer responsibilities, worker training, health surveillance	The principal international instrument for ensuring occupational safety
ILO Safety and Health in Mines Recommendation, 1995 (No. 183)	1995	Provide practical recommendations	Improvement of occupational safety management systems	Complements the provisions of Convention No. 176
ILO *Safety and Health in Opencast Mines*	2018	Provide guidance on safe opencast mining operations	Safety of work, equipment, and transport in open-pit mines	Supports the practical implementation of ILO requirements
ISO 45001:2018	2018	Establish an occupational health and safety management system	Risk-based management, leadership, worker participation, continual improvement	International standard for occupational safety and health management
ILO Occupational Health Services Convention, 1985 (No. 161)	1985	Establish occupational health services	Prevention of occupational diseases and injuries, monitoring of workers' health	Provides a framework for organizing occupational health services at enterprises
WHO/ICOH guidance	2022	Provide an ethical and scientific framework for occupational health	Fitness-for-work criteria, medical examinations, rehabilitation	Provides a scientific basis for organizing medical screening

The comparison presented in Table 1 showed that the functions of the international documents are complementary and clearly differentiated. While the ILO instruments establish the legal and sector-specific framework for occupational safety, ISO 45001:2018 provides a structured model for managing occupational risks at the organizational level. WHO and ICOH recommendations complement this framework by addressing the protection of workers' health through medical surveillance and preventive measures. Thus, a key feature of the international approach is the integration of legal regulation, occupational risk management, and medical surveillance of occupational health into a unified system rather than focusing solely on the control of individual hazards [5-12].

The analysis of occupational risks in the mining industry showed that workers are simultaneously exposed to multiple workplace factors. Among them, respirable occupational dust, noise, and vibration are the most consistently studied hazards. In addition, chemical substances, adverse microclimatic conditions, high physical workloads, and psychosocial factors may also affect workers' occupational health [13-18].

Among occupational dust exposures, respirable particles containing crystalline silica are of particular concern. Studies have shown that prolonged exposure to such particles is associated with pneumoconiosis, silicosis, and chronic obstructive pulmonary disease [10, 13, 14, 19]. At the same time, recent research has increasingly shifted from describing individual diseases toward the integrated assessment of dust concentrations, duration of exposure, and the effectiveness of engineering control measures [10, 19].

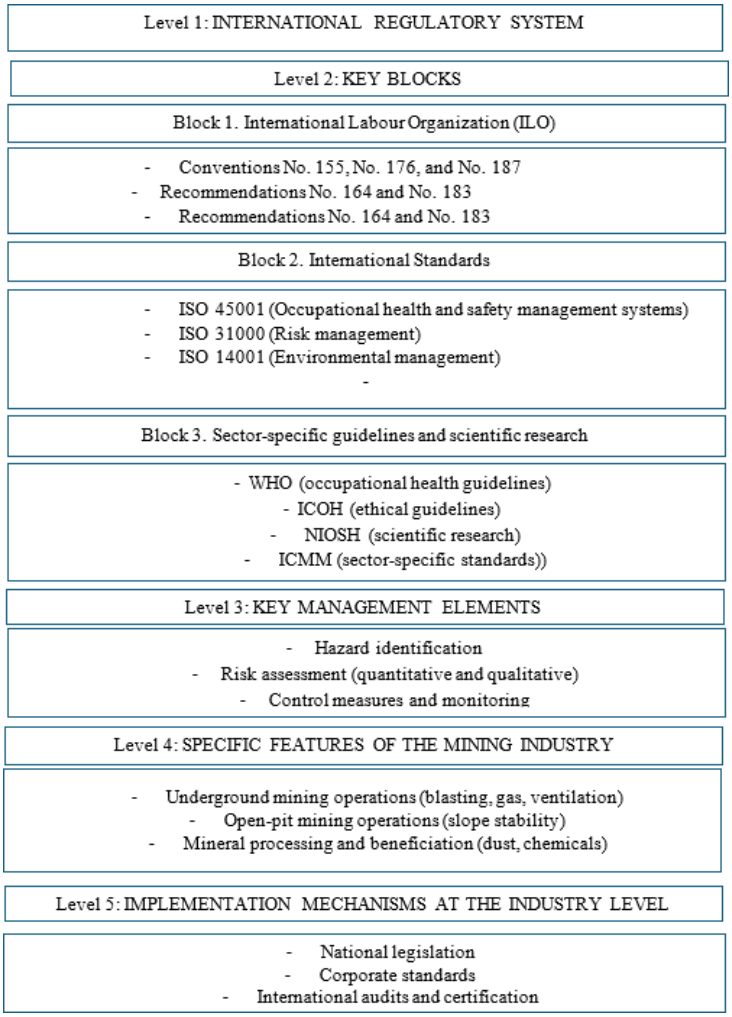


Fig. 1 - International framework for managing occupational risks and protecting the health of mining workers

Noise and vibration are also important occupational hazards in mining. Long-term exposure to excessive noise increases the risk of occupational hearing loss, whereas vibration exposure is associated with disorders of the circulatory, nervous, and musculoskeletal systems [18-20]. Therefore, the assessment of workplace hazards

should not be limited to measuring their individual exposure levels but should also account for exposure duration, intensity, and the simultaneous effects of multiple factors.

The analysis of international regulatory documents and scientific and methodological recommendations made it possible to systematize the main levels and interconnected elements of occupational risk management and occupational health protection in the mining industry. Their structural relationships are presented in Figure 1.

Figure 1 illustrates that the international regulatory and methodological framework for occupational risk management in the mining industry consists of several interconnected levels. The system is based on ILO documents, ISO standards, and sector-specific and scientific recommendations issued by international organizations. Their implementation includes hazard identification, occupational risk assessment, development of control measures, and monitoring of the work environment. This approach is aimed at preventing occupational injuries and diseases and promoting a strong safety culture within mining enterprises [5-9].

Occupational risks in the mining industry are characterized by the combined effects of physical, chemical, biological, ergonomic, and psychosocial factors present in the work environment. Compared with many other industrial sectors, mining workers are typically exposed to multiple hazardous factors simultaneously. This substantially increases the risk of occupational diseases, workplace injuries, and premature loss of work capacity [4, 13]. Similar findings have been reported in studies conducted by Kazakhstani researchers, which demonstrated the combined impact of workplace factors on workers' health [14]. Contemporary research places particular emphasis on occupational dust exposure because of its widespread occurrence and its significant adverse effects on the respiratory system, making it one of the most important occupational hazards in the mining industry.

Effects of Occupational Dust on Workers' Health

The greatest health risk is associated with respirable dust containing crystalline silica. Long-term exposure to such dust can lead to pneumoconiosis, silicosis, chronic obstructive pulmonary disease (COPD), and other respiratory disorders. Despite advances in mineral extraction technologies and the implementation of modern dust-suppression methods, controlling airborne dust concentrations in the workplace remains a major challenge in many countries [10, 13, 15].

In a review conducted by Duarte and colleagues, studies on mineral dust exposure among mining and quarrying workers were analyzed. The authors noted that contemporary research has shifted from evaluating individual occupational diseases toward a comprehensive assessment of dust exposure levels, working conditions, and the effectiveness of engineering controls aimed at reducing occupational risks. Particular attention was paid to the need for continuous monitoring of respirable dust concentrations, improvement of ventilation systems, advancement of dust-control technologies, and strengthening of industrial hygiene measures [10].

Li and colleagues, in a study involving workers exposed to different types of occupational dust, found that prolonged exposure to silica-containing dust has the most detrimental effects on human health. The authors demonstrated statistically significant associations between duration of occupational exposure, workplace dust levels, pathological changes in the respiratory system, impaired lung function, cardiovascular diseases, and hearing loss. Furthermore, the probability of developing occupational pathology increased significantly among workers with more than ten years of exposure and under conditions of high dust intensity [15].

These findings are consistent with the conclusions reported by Donoghue, who emphasized that respiratory diseases continue to occupy a leading position in the structure of occupational pathology among mining workers despite technological improvements and stricter occupational safety requirements [13]. Similar conclusions were presented by Leung and colleagues, who reported that exposure to crystalline silica remains one of the primary causes of silicosis. Silicosis continues to be among the most prevalent occupational respiratory diseases in industries involving exposure to silica-containing dust [14].

The analysis of recent scientific literature indicates that research has evolved from focusing on individual respiratory diseases toward a comprehensive evaluation of the effects of occupational dust on multiple physiological systems. This trend highlights the need for continuous monitoring of respirable dust concentrations, improvement of engineering dust-control measures and ventilation systems, and implementation of risk-based approaches to occupational risk management in mining enterprises.

Effects of Physical Factors in the Work Environment

In addition to occupational dust, physical factors in the workplace pose substantial risks to the health of mining workers. These factors include occupational noise, whole-body and hand-arm vibration, adverse microclimatic conditions, insufficient workplace lighting, and high physical workloads. The combined effects of these exposures increase the risk of occupational disorders affecting the auditory, musculoskeletal, cardiovascular, and nervous systems, while also contributing to reduced work capacity [16-19].

One of the most widespread adverse factors is occupational noise generated by drilling equipment, crushing systems, mining machinery, ventilation installations, and transport vehicles. According to Azman and Jamir, long-term exposure to noise levels exceeding permissible limits significantly increases the risk of occupational hearing loss, impairs concentration, elevates stress levels, and reduces worker productivity [16]. Similar findings have been reported by the U.S. National Institute for Occupational Safety and Health (NIOSH), which identifies noise reduction as one of the priority areas for improving occupational safety in the mining industry [17].

Occupational vibration is another important hazard. It is generated during the operation of drilling rigs, excavators, haul trucks, and other heavy equipment. Prolonged exposure to vibration may lead to peripheral circulatory disorders, musculoskeletal damage, spinal diseases, and functional disorders of the nervous system. Recent studies emphasize the importance of technical measures for vibration reduction, equipment design improvements, and the optimization of work-rest schedules for exposed workers [18].

Mining operations are also characterized by exposure to adverse microclimatic conditions, particularly during surface mining activities conducted under extreme temperatures. The combination of high physical workloads and thermal stress contributes to fatigue, decreased performance, and an increased likelihood of errors during work operations. Consequently, the risk of occupational accidents rises significantly under such conditions [19].

Overall, contemporary research demonstrates that physical workplace factors exert a complex and multifaceted impact on the health of mining workers. Effective prevention of occupational diseases and workplace injuries requires engineering, organizational, and occupational hygiene measures aimed at reducing noise and vibration levels, improving working conditions, maintaining continuous monitoring of environmental parameters, and implementing medical screening programs for workers exposed to physical hazards.

Integrated Approaches to Occupational Risk Assessment

Modern approaches to occupational risk assessment in the mining industry are based on comprehensive evaluations of working conditions that consider the combined effects of physical, chemical, ergonomic, and psychosocial factors. Unlike traditional methods focused on individual workplace hazards, contemporary research emphasizes integrated risk assessment through the application of statistical models, multicriteria assessment techniques, and risk-based management systems [4, 20].

According to Zhang and colleagues, the health status of mining workers is determined not by a single occupational factor but by the cumulative effects of multiple exposures. The authors identified occupational dust, excessive noise, nitrogen oxides, heavy metals, vibration, adverse microclimatic conditions, awkward working postures, and psychosocial stressors as the most significant risk factors. These findings support the necessity of adopting a multifactorial approach when assessing occupational risks and developing preventive measures [4].

The results are consistent with the conclusions of Bekmagambetov and colleagues, who identified causal relationships between working conditions and the development of occupational diseases using an industrial enterprise in the Republic of Kazakhstan as a case study. The authors demonstrated that a risk-based approach enables a more objective assessment of the impact of workplace factors on workers' health and facilitates the development of effective preventive measures [21].

In a scoping review of occupational injuries in the mining industry, Cruz-Ausejo and colleagues identified insufficient occupational risk assessment, non-compliance with safety requirements, inadequate worker training, poor technical condition of equipment, and ineffective workplace supervision as the most common causes of occupational accidents [20].

The analysis of contemporary scientific literature indicates that the most effective occupational risk management systems are those that integrate international standards, quantitative risk assessment methods, and digital technologies for workplace monitoring. A comprehensive risk-based approach facilitates the timely identification of hazards, reduces the likelihood of occupational injuries and diseases, and

contributes to the preservation of workers' health in the mining industry.

In this context, modern monitoring technologies, including wearable sensors, personal monitoring devices, and stationary systems, can be used for continuous assessment of dust, noise, vibration, and microclimatic conditions. Quantitative risk assessment can combine exposure intensity and duration with the probability and severity of adverse outcomes, allowing high-risk workplaces and occupational groups to be prioritized. For mining enterprises in Kazakhstan, the integration of such technologies with existing occupational safety management systems can improve the timeliness and objectivity of risk assessment and support evidence-based preventive measures.

The reviewed studies employ different methodological approaches to occupational risk assessment in the mining industry. Some investigations focus primarily on occupational dust exposure and its health effects, whereas others address the multifactorial nature of occupational risks and the organizational causes of workplace injuries. The characteristics and principal findings of the key studies are summarized in Table 2.

Table 2 - Contemporary studies on occupational risks and occupational health of mining workers

Author	Year	Study subject	Research method	Main findings
Duarte J. et al.	2022	Exposure to mineral dust	Literature review	Occupational dust is a major occupational risk factor
Li M. et al.	2025	Workers exposed to occupational dust	Cross-sectional study	An association was identified between the duration of dust exposure and the development of occupational diseases
Zhang B. et al.	2024	Risk factors in the mining industry	Multifactorial analysis	The combined effects of occupational dust, noise, and vibration were identified
Cruz-Ausejo L. et al.	2024	Occupational injuries	Scoping review	Organizational and technical risk factors were identified

A comparison of the studies presented in Table 2 demonstrates the multifactorial nature of occupational risks in the mining industry. The review by Duarte et al. showed that occupational dust remains a persistent occupational hazard in mining and earthmoving activities [10], whereas Li et al. assessed the relationship between the duration of dust exposure and workers' health status [18]. These findings indicate that occupational dust should be monitored not only as an individual risk factor but also with consideration of the duration and intensity of exposure.

The study by Zhang et al. demonstrated that workers' occupational health is affected by the simultaneous exposure to multiple workplace factors, supporting the importance of multifactorial risk assessment [4]. The review by Cruz-Ausejo et al. showed that occupational injuries are associated not only with workplace hazards but also with organizational and technical conditions [20].

Comparison of these studies identified three interrelated areas that should be considered when assessing occupational risks in the mining industry: the level and duration of exposure to workplace hazards; the combined effects of multiple hazardous factors; the influence of organizational and technical conditions on occupational injuries.

The practical implementation of international requirements in the field of occupational safety and occupational health in the mining industry is achieved through the introduction of occupational risk management systems based on the principles of the International Labour Organization (ILO) and the requirements of ISO 45001:2018 [5, 8]. In most industrialized countries, occupational safety is considered not merely as compliance with legal requirements, but as an integral component of corporate management aimed at preventing occupational injuries, protecting workers' health, and ensuring sustainable enterprise development [1, 4].

Australia, Canada, the United States, and the European Union have accumulated extensive experience in implementing modern occupational safety management systems. Enterprises in these countries widely apply a risk-based approach that includes continuous hazard identification, occupational risk assessment, development of preventive measures, and continuous improvement of occupational safety and occupational health management systems. Particular attention is also given to active worker participation in safety management processes, systematic personnel training, and the development of a safety culture at all organizational levels [4, 11, 12].

According to Podrecca et al., the implementation of ISO 45001 has a positive effect not only on occupational safety performance but also on the overall performance of enterprises. The authors found that organizations implementing modern occupational safety and occupational health management systems demonstrate improved sustainability performance, reduced rates of occupational injuries, and more effective occupational risk management. The most pronounced positive effects were observed in enterprises with high levels of occupational hazards, including the mining industry [20].

The practical application of ISO 45001:2018 in Kazakhstani mining enterprises can be organized through a continuous risk-management cycle based on the Plan–Do–Check–Act principle. At the planning stage, enterprises should identify hazards associated with mining operations, including respirable dust, noise, vibration, chemical agents, thermal stress, physical workload, machinery, transportation, and psychosocial factors, and evaluate the corresponding occupational risks. The implementation stage should prioritize the hierarchy of controls, giving preference to elimination and engineering controls over administrative measures and personal protective equipment. The checking stage should include regular monitoring of workplace exposures, occupational incidents, near misses, workers' health indicators, and compliance with established risk-control measures. At the improvement stage, the results should be reviewed by management and used to revise risk assessments, preventive measures, training programs, and emergency procedures.

For mining enterprises in Kazakhstan, ISO 45001 can therefore serve not only as a certification framework but also as an operational management tool. Its effectiveness would be increased by integrating occupational hygiene measurements, medical surveillance, digital monitoring systems, contractor safety management, and worker participation into the same occupational health and safety management system. This approach would facilitate the transition from reactive responses to accidents and occupational diseases toward proactive prevention based on early identification and control of occupational risks.

The International Labour Organization plays an important role in advancing international practices. The organization implements initiatives aimed at developing a safety culture, strengthening social dialogue, and improving national occupational safety management systems. Particular attention is given to worker training, improving employers' competencies, developing occupational risk assessment methods, organizing medical surveillance, and preventing occupational diseases. In recent years, the ILO has also implemented initiatives aimed at improving occupational safety in the mining industries of developing countries, including the countries of Central Asia [5-7].

Analysis of international experience indicates that the most effective occupational safety management systems are based on the integrated application of international regulatory requirements, a risk-based approach, and the principles of continuous improvement. Active worker participation in hazard identification, systematic occupational risk assessment, development of a safety culture, and regular personnel training make a significant contribution to improving occupational safety.

At the same time, analysis of scientific publications indicates that the implementation of international standards in mining enterprises is accompanied by a number of organizational and economic challenges. The main limiting factors include insufficient financial resources, differences in national regulatory systems, a shortage of qualified specialists in occupational safety and occupational health, and insufficient digitalization of workplace monitoring and control processes. Despite these limitations, international experience demonstrates that integrating ILO requirements, ISO 45001:2018 provisions, and modern occupational risk management methods can contribute to reducing occupational injuries and diseases in mining enterprises and improving the effectiveness of occupational safety management systems.

The mining industry of the Republic of Kazakhstan is one of the leading sectors of the national economy and is characterized by high levels of exposure to hazardous and harmful workplace factors. According to the Bureau of National Statistics of the Republic of Kazakhstan, 298.3 thousand people were employed in the mining and quarrying sector in the first quarter of 2026, representing a 3.4% increase compared with the same period of 2025 [22]. In 2025, 2,328 work-related accidents were registered in Kazakhstan, including 130 workers injured in the mining industry, while 408 cases of occupational diseases were registered nationwide [23]. Studies conducted by Kazakhstani researchers identify occupational dust, noise, vibration, adverse microclimatic conditions, and high physical workloads among the most significant factors affecting workers' health. This confirms the need to further improve occupational risk management systems and introduce modern preventive approaches based on international experience [17]. In this regard, the application of

international standards and advanced international practices is considered one of the priority directions for improving the effectiveness of occupational injury and disease prevention [8, 10, 11].

Table 3 - International experience in implementing occupational safety management systems in the mining industry

Country (or region)	Main approach	Applicable international documents	Main outcomes
Australia	Risk-based management	ISO 45001, ILO	Reduction in occupational injury rates; development of a safety culture
European Union	Integrated management systems	ISO 45001, EU Directives	Improvement of occupational risk assessment systems
United States	Workplace monitoring and control	NIOSH, ISO 45001	Reduction of exposure to hazardous workplace factors
China	Risk-based safety management, hazard identification and monitoring	National mining safety regulations, occupational disease prevention requirements	Strengthening safety responsibility, risk prevention and monitoring of mining operations
Kazakhstan (ILO-implemented projects)	Harmonization with international requirements	ILO Conventions, ILO projects	Development of social dialogue and improvement of the occupational safety system

In recent years, the Republic of Kazakhstan has undertaken systematic efforts to improve the regulatory and legal framework in the field of occupational safety, taking into account international requirements. The development of a risk-based approach, the introduction of modern occupational risk management systems, and the expansion of ISO 45001 implementation in large industrial enterprises indicate the gradual alignment of the national occupational safety system with international requirements [8, 14].

Cooperation between the Republic of Kazakhstan and the International Labour Organization (ILO) plays an important role in this process. Ongoing projects are aimed at developing social dialogue, improving occupational risk assessment methods, enhancing the qualifications of specialists, introducing modern approaches to the prevention of occupational injuries and diseases, and improving systems for medical surveillance of workers' health. Particular attention is also given to developing a safety culture, improving preventive measures, and increasing the effectiveness of state and workplace monitoring of working conditions [5-7].

Despite the progress achieved, analysis of the scientific literature and international experience indicates that several factors continue to limit the full implementation of international approaches in domestic enterprises. These findings are consistent with the results of the study by Bekmagambetov et al., which confirmed a causal relationship between adverse working conditions and the development of occupational diseases in industrial enterprises in Kazakhstan [24]. The main challenges include differences in the level of development of occupational safety management systems across enterprises, insufficient implementation of modern occupational risk assessment methods in workplace practice, limited capacity of occupational health services, as well as the need for further professional development of specialists and improvement of preventive programs [8].

One of the promising directions for developing the national occupational safety system is the further implementation of risk-based management based on international standards and modern scientific approaches to occupational risk assessment [4, 11]. Recent studies also emphasize the need to improve the classification of working conditions and worker categories while taking into account the introduction of new production technologies, digitalization of industrial processes, and the principles of sustainable development [25]. In addition, particular importance should be given to developing modern occupational risk assessment

methods, improving medical surveillance systems for workers, strengthening the safety culture, enhancing the human-resource capacity of occupational safety services, and expanding cooperation among government authorities, employers, research organizations, and workers [4, 20].

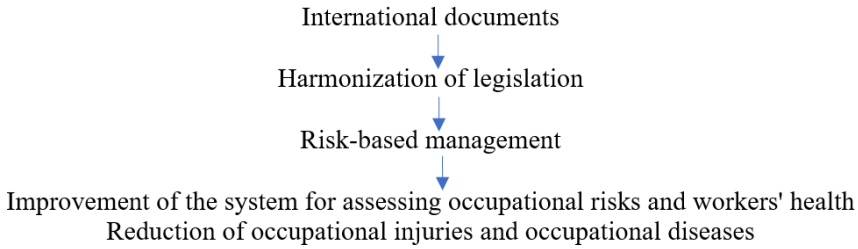


Fig. 2 - Key directions for improving the occupational safety system in the mining industry of the Republic of Kazakhstan based on international experience

Implementation of international approaches in the national occupational safety system

The implementation of the main directions for integrating international approaches into the national occupational safety system should not be limited to improving the regulatory and legal framework. It should also focus on developing modern approaches to the management of occupational risks and workers' occupational health, improving methods for assessing occupational risks and occupational health, developing occupational health services at enterprises, enhancing the professional competencies of specialists, fostering a safety culture, and strengthening social partnership in the field of occupational safety.

Results and Discussion. An analysis of the current scientific literature showed that ensuring occupational safety and protecting the occupational health of mining workers are increasingly based on a risk-based approach that involves a comprehensive assessment of working conditions and continuous management of occupational risks. Analysis of international regulatory documents and scientific publications demonstrated that the requirements of the International Labour Organization (ILO), the World Health Organization (WHO), the International Commission on Occupational Health (ICOH), and ISO 45001:2018 form a common methodological basis for modern occupational safety management systems, while their effectiveness is supported by findings from studies conducted in different countries [5, 8, 11, 12].

Unlike earlier studies that primarily focused on individual occupational hazards, recent research considers occupational risks as the result of the combined effects of physical, chemical, ergonomic, organizational, and psychosocial factors in the working environment. This approach allows for a more objective assessment of working conditions and provides a basis for developing comprehensive preventive measures aimed at preventing occupational injuries and diseases. The findings are consistent with the conclusions of Bekmagambetov et al., who confirmed the relationship between working conditions and the development of occupational diseases in industrial enterprises in the Republic of Kazakhstan, as well as with the findings of Aktaeva et al., who demonstrated the combined effects of occupational factors on the health of mining workers [21, 23].

The review showed that the most effective management systems are those that integrate the requirements of international standards, quantitative occupational risk assessment methods, engineering preventive measures, medical surveillance, and active worker participation in ensuring occupational safety. At the same time, the effectiveness of implementing such systems largely depends on the level of development of national legislation, the organizational culture of enterprises, the availability of qualified specialists, and access to modern technologies for occupational monitoring. These factors largely explain differences in the effectiveness of implementing international approaches between industrialized and developing countries.

The Chinese experience further demonstrates that the practical implementation of risk-based occupational safety management requires not only regulatory requirements but also clearly assigned responsibilities, systematic workplace monitoring, regular inspections, and continuous hazard prevention.

A comparison of international approaches with the current occupational safety system in the Republic of Kazakhstan indicates that the main principles of risk-based management are incorporated into the national regulatory framework. Kazakhstan's legislation requires occupational risk assessment, monitoring of working conditions, implementation of occupational safety management systems, and corrective measures.

The national approach is therefore generally consistent with the preventive principles of ILO instruments and ISO 45001:2018. However, the practical integration of these principles into enterprise-level management remains less consistent. International mining practices increasingly link risk assessment with operational decision-making, worker participation, emergency preparedness, and continuous improvement, while their implementation in Kazakhstan varies among enterprises depending on organizational capacity, qualified personnel, technologies, and safety culture.

For Kazakhstan's mining industry, international approaches should therefore be adapted to national legislation and specific mining conditions. Particular attention should be given to integrating workplace monitoring, occupational risk assessment, medical surveillance, and preventive measures into a single management cycle to support a more proactive, evidence-based approach to occupational safety.

One of the main limitations of this review is the limited number of recent studies addressing occupational risks among mining workers in Central Asian countries, including the Republic of Kazakhstan. Most published studies have been conducted in Europe, North America, and Australia, which limits the direct applicability of their findings to regional conditions. In addition, a lack of comprehensive epidemiological studies assessing the combined effects of occupational factors on the health of mining workers in Kazakhstan was identified [4, 21-24].

The main strength of this review is the comprehensive analysis of international regulatory documents, recent scientific studies, and national publications. This made it possible to systematize modern approaches to occupational risk management and identify promising areas for improving the national occupational safety system. The findings can be used to develop risk-based models for occupational risk management at mining enterprises in the Republic of Kazakhstan, improve the regulatory and legal framework, and introduce modern approaches to the prevention of occupational diseases.

Conclusion. A systematic review of international regulatory documents and recent scientific studies showed that effective occupational safety and protection of the occupational health of mining workers should be based on a risk-based approach involving comprehensive hazard identification, occupational risk assessment, implementation of preventive measures, and continuous improvement of occupational safety management systems in accordance with international standards [4, 8, 11, 12, 22, 23].

The analysis of the scientific literature showed that the most effective management systems integrate ILO requirements, the provisions of ISO 45001:2018, the recommendations of the World Health Organization and the International Commission on Occupational Health (ICOH), modern occupational risk assessment methods, engineering control measures, medical surveillance, and the development of a safety culture. The comprehensive application of these approaches contributes to reducing occupational injuries and diseases and improving the operational efficiency of mining enterprises [5, 8, 20].

The review findings indicate that, for the Republic of Kazakhstan, further improvement of the national occupational safety system should focus on the wider implementation of risk-based management, harmonization of the regulatory and legal framework with international requirements, improvement of occupational risk assessment methods, development of occupational health services, and enhancement of the effectiveness of preventive measures, taking into account the specific characteristics of the domestic mining industry [4, 24, 25].

At the enterprise level, priority should be given to regular occupational risk assessment, continuous monitoring of hazardous workplace factors, strengthening engineering controls, and integrating the results of workplace monitoring with medical surveillance. Occupational health services should focus on early detection of occupational diseases, risk-oriented medical examinations, monitoring of workers exposed to high-risk factors, and participation in the development of preventive measures. These measures would strengthen the practical implementation of risk-based occupational safety management in mining enterprises in Kazakhstan.

The analysis identified the insufficient number of comprehensive studies on occupational risks among mining workers in Central Asian countries as one of the main limitations of current scientific knowledge. This highlights the need for further epidemiological studies, development of scientifically based methods for comprehensive occupational risk assessment, adaptation of international approaches to the conditions of the Republic of Kazakhstan, and implementation of digital technologies for monitoring working conditions.

The analysis of international practices, including the experience of China, demonstrates the importance of combining regulatory requirements with systematic risk identification, workplace monitoring, preventive measures, and clearly defined safety responsibilities. For Kazakhstan, these approaches should be adapted

to national legislation and the specific conditions of the mining industry, taking into account the current occupational injury and occupational disease situation.

The findings may be used to improve public policy in the field of occupational safety, develop corporate occupational risk management systems, train occupational safety specialists, and formulate scientifically based recommendations for mining enterprises.

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