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COLLECTIVE PROTECTION MEASURES IN THE OCCUPATIONAL RISK MANAGEMENT SYSTEM: A COMPARATIVE ANALYSIS OF APPROACHES IN KAZAKHSTAN, THE EU, GERMANY AND THE USA

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The article presents a comparative legal and regulatory analysis of the framework governing the use of collective protective equipment (CPE) for workers of the chemical industry exposed to chemical factors in the Republic of Kazakhstan, the European Union, the Federal Republic of Germany, and the United States. The relevance of the study stems from the elevated occupational risks associated with chemical production, which are conditioned by the toxicity, fire and explosion hazards of the substances involved, as well as by the substantial social and economic losses caused by occupational injuries and diseases.

The purpose of the present research is to conduct a comparative regulatory and legal analysis of the role of collective protective equipment in preventing occupational risks arising from exposure to chemical factors, drawing on the approaches adopted in the European Union, the Federal Republic of Germany, the United States, and the Republic of Kazakhstan.

The findings demonstrate that all of the systems examined are oriented toward preventing exposure to hazardous substances through risk management, yet the extent to which CPE is integrated into design and operation differs considerably. In the EU and Germany, protective measures are embedded at the design stage on the basis of a mandatory risk assessment carried out prior to the commencement of activity, with priority given to engineering and collective solutions. In the United States, the standards prescribe detailed requirements for specific technological processes, mandating hazard analysis and the deployment of engineering barriers. Kazakhstan is currently transitioning from a compensation-based model to a risk-oriented one, although the linkage between risk assessment, engineering design, and digital monitoring remains insufficiently developed.

The discussion highlights the need to reinforce the priority of CPE within the hierarchy of protective measures, to expand the use of automated control and intelligent monitoring systems, and to elaborate criteria for selecting CPE according to the type of chemical factor, the technological process, and the level of exposure.

The conclusions provide the grounds for recommendations to improve Kazakhstan's legislation: the technical regulations should be supplemented with requirements concerning containment, ventilation, gas analysis, automation, and emergency systems, and the results of risk assessment should be integrated into the design and modernization of production facilities. It is proposed to shift from the formal availability of protective equipment to the assessment of its actual effectiveness against specific chemical risks, in line with modern international

standards ISO 45001 and ISO 31000.

Keywords: chemical factors, chemical production, collective protective equipment, occupational risk, risk-oriented approach, harmful and hazardous production factors, occupational safety and health.

КӘСІБИ ТӘУЕКЕЛДЕРДІ БАСҚАРУ ЖҮЙЕСІНДЕГІ ҰЖЫМДЫҚ ҚОРҒАНЫС ҚҰРАЛДАРЫ: ҚАЗАҚСТАН, ЕО, ГЕРМАНИЯ ЖӘНЕ АҚШ ТӘСІЛДЕРІН САЛЫСТЫРМАЛЫ ТАЛДАУ

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Мақала Қазақстан Республикасында, Еуропалық одақта, Германияда және АҚШ-та химия өнеркәсібі жұмысшыларын химиялық факторлардың әсерінен қорғаудың ұжымдық қорғау құралдарын (ҰҚҚ) қолдануды нормативтік-құқықтық реттеуді салыстырмалы талдауға арналған. Зерттеудің өзектілігі химиялық өндірістегі заттардың улылығы, өрт және жарылыс қауіптілігімен байланысты жоғары кәсіби тәуекелдермен, сондай-ақ өндірістік жарақаттану мен кәсіптік аурулардан болатын елеулі әлеуметтік және экономикалық шығындармен айқындалады.

Осы зерттеудің мақсаты – Еуропалық одақтың, Германия Федеративтік Республикасының, АҚШ-тың және Қазақстан Республикасының тәсілдерін ескере отырып, химиялық факторлардың әсерінен болатын кәсіби тәуекелдердің алдын алудағы ұжымдық қорғау құралдарының рөліне салыстырмалы нормативтік-құқықтық талдау жүргізу болып табылады.

Нәтижелер барлық қарастырылып отырған жүйелердің қауіпті заттардың әсерін тәуекелдерді басқару арқылы алдын алуға бағытталғанын көрсетеді, алайда ҰҚҚ-ның жобалау мен пайдалануға кіріктірілу дәрежесі әртүрлі. ЕО-да және Германияда қорғаныш шаралары жобалау сатысында іс-әрекет басталғанға дейін міндетті тәуекелдерді бағалау негізінде қаланады, инженерлік және ұжымдық шешімдерге басымдық беріледі. АҚШ-та стандарттар нақты технологиялық процестерге қойылатын талаптарды егжей-тегжейлі белгілеп, қауіптерді талдауды және инженерлік тосқауылдарды қолдануды талап етеді. Қазақстан өтемдік модельден тәуекел-бағдарланған модельге көшу сатысында, бірақ тәуекелдерді бағалаудың жобалаумен және цифрлық мониторингпен байланысы әлі жеткілікті дамымаған.

Талқылау қорғаныш шаралары иерархиясында ҰҚҚ-ның басымдығын күшейту, автоматтандырылған бақылау жүйелері мен интеллектуалды мониторингті қолдануды кеңейту, сондай-ақ химиялық фактордың түріне, технологиялық процеске және әсер ету деңгейіне байланысты ҰҚҚ таңдау критерийлерін әзірлеу қажеттілігін анықтайды.

Қорытындылар қазақстандық заңнаманы жетілдіру бойынша ұсынымдарды негіздейді: герметизацияға, желдетуге, газды талдауға, автоматтандыруға және авариялық жүйелерге қойылатын талаптармен нормативтерді толықтыру, сондай-ақ тәуекелдерді бағалау нәтижелерін өндірістерді жобалауға және жаңғыртуға кіріктіру. Қорғаныш құралдарының формальды түрде болуынан нақты химиялық тәуекелдер кезінде олардың

нақты тиімділігін бағалауға көшуді ұсынылады, бұл ISO 45001 және ISO 31000 халықаралық стандарттарына сәйкес келеді.

Түйін сөздер: химиялық факторлар, химиялық өндіріс, ұжымдық қорғау құралдары, кәсіби тәуекел, тәуекелге бағдарланған тәсіл, зиянды және қауіпті өндірістік факторлар, еңбекті қорғау.

СРЕДСТВА КОЛЛЕКТИВНОЙ ЗАЩИТЫ В СИСТЕМЕ УПРАВЛЕНИЯ ПРОФЕССИОНАЛЬНЫМИ РИСКАМИ: СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПОДХОДОВ КАЗАХСТАНА, ЕС, ГЕРМАНИИ И США

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Статья посвящена сравнительному анализу нормативно-правового регулирования применения средств коллективной защиты (СКЗ) работников химической промышленности от воздействия химических факторов в Республике Казахстан, Европейском союзе, Германии и США. Актуальность исследования обусловлена высокими профессиональными рисками в химическом производстве, связанными с токсичностью, пожаро- и взрывоопасностью веществ, а также значительными социальными и экономическими потерями от производственного травматизма и профзаболеваний.

Целью настоящего исследования является проведение сравнительного нормативно-правового анализа роли средств коллективной защиты в предупреждении профессиональных рисков, обусловленных воздействием химических факторов, с учетом подходов Европейского союза, Федеративной Республики Германии, США и Республики Казахстан.

Результаты показывают, что все рассматриваемые системы ориентированы на предупреждение воздействия опасных веществ через управление рисками, однако степень интеграции СКЗ в проектирование и эксплуатацию различается. В ЕС и Германии защитные меры закладываются на этапе проектирования на основе обязательной оценки рисков до начала деятельности, приоритет отдаётся инженерным и коллективным решениям. В США стандарты детализируют требования к конкретным технологическим процессам, требуя анализа опасностей и применения инженерных барьеров. Казахстан находится на этапе перехода от компенсационной к риск-ориентированной модели, но связь оценки рисков с проектированием и цифровым мониторингом ещё недостаточно развита.

Обсуждение выявляет необходимость усиления приоритета СКЗ в иерархии защитных мер, расширения применения автоматизированных систем контроля и интеллектуального мониторинга, а также разработки критериев выбора СКЗ в зависимости от вида химического фактора, технологического процесса и уровня экспозиции.

Выводы обосновывают рекомендации по совершенствованию казахстанского законодательства: дополнить нормативы требованиями к герметизации, вентиляции, газоаналитике, автоматизации и аварийным системам, а также интегрировать результаты оценки рисков в проектирование и модернизацию производств. Предлагается перейти от формального наличия средств защиты к оценке их фактической эффективности при конкретных химических рисках, что соответствует современным международным стандартам ISO 45001 и ISO
31000.

Ключевые слова: химические факторы, химическое производство, средства коллективной защиты, профессиональный риск, риск-ориентированный подход, вредные и опасные производственные факторы, охрана труда.

Introduction. Under the current conditions of chemical-industry development, ensuring safe working conditions has become one of the central directions of occupational safety and industrial safety. Chemical production is characterized by the use of toxic, flammable, explosive, corrosive, and other substances capable of exerting both acute and chronic effects on workers' health [1, 2]. Particular danger is posed by emergency releases of toxic substances, leaks of gases and vapours, the formation of hazardous concentrations of chemical agents, and the dispersion of toxic clouds. Exposure to chemical factors may occur both under normal operating conditions and as a consequence of loss of equipment tightness, malfunctions of technological systems, or emergencies.

For this reason, the protection of chemical-industry workers must rest not only on the use of personal protective equipment (PPE), but above all on preventing and containing the hazard directly at its source through engineering and collective protective measures. Such measures include sealing of process equipment, automation of processes, local and emergency ventilation systems, monitoring of gas

contamination, automatic shut-off of reagent supply, and systems for containing and neutralizing emissions [3, 4]. Their use simultaneously reduces the exposure of a group of workers to chemical factors and lessens the dependence of the level of protection on individual behaviour and on the correct use of PPE.

CPE and PPE thereby function as mutually complementary elements of the protection system. PPE is used to protect workers against residual risk, in particular during repair, technological, and emergency work. Nevertheless, where technical capability exists to eliminate or contain the hazard, the question arises of the legal priority of collective protective measures. In international practice, this principle is implemented through the hierarchy of occupational risk controls, which prescribes the preferential use of measures aimed at eliminating the hazard or reducing its impact at the source [5-7].

In this connection, particular importance attaches to the legal and regulatory framework governing the selection and use of CPE, the definition of employer obligations, and the establishment of requirements for monitoring their effectiveness. Comparing the corresponding approaches allows the common principles and divergences in the regulation of collective protection of chemical-industry workers to be identified.

The purpose of the present study is to carry out a comparative regulatory and legal analysis of the role of collective protective equipment in preventing occupational risks arising from exposure to chemical factors, with reference to the approaches of the European Union, the Federal Republic of Germany, the United States, and the Republic of Kazakhstan.

Materials and methods. The materials of the study comprised scientific publications, regulatory legal acts, international standards, technical regulations, and methodological documents governing the management of occupational risks and the use of collective protective equipment for workers exposed to chemical factors. The scientific literature was analysed on the basis of publications indexed in the electronic libraries eLibrary and CyberLeninka, as well as in the international databases PubMed, Scopus, Web of Science, MEDLINE, and RSCI.

The regulatory and legal analysis covered the legislative and normative instruments of the Republic of Kazakhstan, the European Union, the Federal Republic of Germany, and the United States that govern the requirements for preventing and reducing occupational risks associated with exposure to chemical factors.

The study employed methods of comparative legal, systemic, and structural-functional analysis, together with the classification of collective protective equipment, occupational risk assessment, and the review of technological regulations and design standards for chemical facilities.

Results and discussion. The analysis of the regulatory-legal and methodological approaches to the protection of chemical-industry workers from exposure to chemical factors indicates that contemporary occupational safety systems are oriented primarily toward preventing and reducing occupational risks at the level of the technological process itself. Under chemical-production conditions, collective protective equipment acquires particular importance, since it acts directly upon the source of hazardous substance release, prevents such substances from entering the working area, and simultaneously provides protection for a group of workers.

The principal measures include sealing of process equipment, the use of local and general-exchange ventilation, automatic monitoring of harmful-substance concentrations in the air, emergency shut-off systems, and remote control of technological processes.

The results of the comparative analysis of the legal approaches of the Federal Republic of Germany and the Republic of Kazakhstan reveal a set of common directions in ensuring the safety of chemical-industry workers. Among these are the priority accorded to preventing exposure to chemical factors, the use of technical and collective protective measures, the assessment of occupational risks, the monitoring of working conditions, and the deployment of automated monitoring systems. Emphasis is placed on reducing risk directly at the point where the hazardous factor arises, which allows collective protective equipment to be regarded as the principal technical tier for preventing occupational exposure to chemical substances. Personal protective equipment supplements this system and is employed where exposure to a chemical factor cannot be entirely eliminated by engineering and technical means [8-10].

The practice of foreign states shows that in the chemical industry priority is accorded to technical and collective protective measures aimed at containing the hazardous factor at the point of its origin. The most widely used solutions are local exhaust ventilation, sealing and isolation of technological processes,

mechanization and automation of operations, and the treatment of exhausted air.

Experience of the United States. An illustrative example is provided by Gold Coast Ingredients, Inc. of California, which specializes in the production of food flavourings. The U.S. National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of engineering controls used during the weighing and pouring of chemical substances and during the mixing of large product batches. A local exhaust ventilation (LEV) system had been installed at the enterprise to reduce chemical exposure directly at the points of release. Ventilated workstations were employed for operations involving small batches, whereas fume enclosures were used for large-batch mixing. The NIOSH study demonstrated a high effectiveness of these engineering solutions: the capture efficiency for contaminants amounted to 89–100 per cent for the ventilated workstations and 96-100 per cent for the fume enclosures. The American experience thus demonstrates the feasibility of substantially reducing occupational exposure to chemical substances through engineering collective protective equipment before such substances disperse into the working area [11].

Experience of Germany. In Germany, the experience of protecting workers engaged in the production and processing of styrene-based materials, widely used in the manufacture of polymer and plastic articles, is particularly instructive. Studies by the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA/DGUV) have shown that during the production of polymer articles considerable quantities of styrene vapour may enter the working-zone air. Under certain production conditions, evaporation losses could reach several kilograms per shift per workplace, and the established exposure limit of 86 mg/m³ could be exceeded. As a priority measure, the capture of unavoidable emissions directly at the point of their formation is envisaged, using local exhaust ventilation systems and subsequent treatment of the exhausted air. Particular attention is paid to reducing the volume of exhausted air while maintaining adequate capture effectiveness, since an increase in air flow rate substantially raises the operating costs of purification systems. The German experience demonstrates a comprehensive approach in which collective protection combines source containment, ventilation, and emission treatment [12].

Experience of the European Union (France). A larger-scale assessment of the use of collective protective measures was presented by researchers in France on the basis of the national survey of working conditions SUMER 2017. The analysis covered 4,196 exposure situations of workers involving 25 carcinogenic chemical substances. It was established that in 35.5 per cent of cases collective protection was absent altogether. General-exchange ventilation was used in 25.5 per cent of situations, local exhaust ventilation in 14.5 per cent, and the most effective source-containment measure-enclosure of the process-in only 2.3 per cent. Furthermore, the indicators differed considerably for individual substances. For example, in exposure to formaldehyde local exhaust ventilation was applied in 31.8 per cent of situations, whereas for trichloroethylene the figure was only 3.5 per cent. For wood dust the indicator amounted to 31.5 per cent, for crystalline silica to 12.5 per cent, and for diesel exhaust to 7.0 per cent [13].

The results obtained in France are of fundamental importance for evaluating the effectiveness of the occupational risk management system. Notwithstanding the statutory priority of collective protection, its actual implementation remains insufficient: only about 35 per cent of the examined carcinogen-exposure situations were accompanied by any collective protective measures at all, whereas in a considerable share of cases predominantly general-exchange ventilation was employed, the effectiveness of which for preventing exposure at the source is limited. The researchers also established that situations involving substances with binding occupational exposure limit values (BOELV) were more often accompanied by source-control measures: 18 per cent as against 12 per cent for situations without such a normative value [13-15].

Thus, international experience demonstrates that the most effective forms of collective protection in the chemical industry are the isolation and sealing of the source, local exhaust ventilation, mechanization and automation of technological operations, and the treatment of exhausted air. At the same time, the French data show that the mere existence of a regulatory requirement establishing the priority of collective protection does not in itself guarantee its actual implementation. Accordingly, improvement of the occupational risk management system must be oriented not only toward providing workers with PPE, but above all toward eliminating or containing the hazard at its source.

At the present stage, the development of collective protective equipment is driven by the introduction of digital technologies, automation, and artificial intelligence. Enterprises make extensive use of

intelligent monitoring systems for the production environment, automated complexes for monitoring the concentration of harmful substances, digital ventilation control systems, robotic complexes that remove the human being from the hazardous zone, digital twins of production processes, and machine-learning-based systems for predicting emergency situations. Modern collective protective equipment is becoming part of a unified digital system for managing occupational risks, ensuring continuous monitoring of production-environment parameters and the timely prevention of hazardous events [16, 17].

The contemporary understanding of collective protective equipment has taken shape through decades of development of the international occupational safety system, which rests on the principle of hazard prevention.

At present, a particular role in the system of protecting workers at production sites is played by collective protective equipment against exposure to chemical factors, since it should be regarded as the priority and foundational tier of protection [18, 19].

From a scientific standpoint, collective protective equipment against exposure to chemical factors may most appropriately be regarded as a set of engineering, technical, structural, automated, and organizational solutions intended to prevent or restrict the effect of hazardous and harmful production factors simultaneously on all workers located within the zone of potential hazard. Such a definition most fully reflects the contemporary concept of risk-based occupational safety management, which rests on the prevention of the emergence of occupational risks.

The diversity of production processes, hazardous factors, and technologies has led to the emergence of a variety of approaches to the classification of collective protective equipment. Neither the scholarly literature, nor international standards, nor regulatory documents contain a single universal system of classification; nevertheless, most researchers identify several principal classifying features enabling the existing types of collective protective equipment to be systematized [20, 21].

Within the existing classification of collective protective equipment by the character of the hazardous production factor being protected against, chemical factors-alongside physical, mechanical, and biological ones-are also included, whose principal purpose is to prevent or reduce exposure to harmful and hazardous chemical substances. Collective protective equipment includes: general-exchange and local ventilation systems, aspiration installations, gas-purification facilities, sealed production lines, automated systems for monitoring the concentration of harmful substances, equipment for containing emergency releases, systems for neutralizing toxic compounds, and air purification complexes (Table 1) [22, 23].

Table 1 - Types of collective protective equipment for chemical production

CPE group	Examples	Purpose
Structural and technological	Sealing of reactors, apparatus, pipelines, and fittings; leak-tight connections; seal-less pumps	Prevention of the escape of substances into the working area
Ventilation	Local exhausts; aspiration enclosures; fume hoods; general-exchange and emergency ventilation	Removal or containment of contaminated air
Gas-analytical and automated	Stationary gas detectors; continuous monitoring; automatic interlocks	Early detection of hazards and prevention of accident escalation
Containment and neutralization	Scrubbers, gas-treatment systems, spill collection, neutralization	Reduction and containment of the consequences of a release
Fire and explosion protection	Automatic fire suppression, emergency shut-off, explosion-protection systems	Prevention or limitation of secondary consequences
Remote control	Automated control, remote valves and fittings, offsite operator stations	Removal of the worker from the hazardous zone

For chemical production, the priority of CPE is determined by the necessity of preventing worker contact with a chemical agent directly at the point of its formation or dispersion. CPE makes it possible to monitor the source of the hazard, prevent the dispersal

of toxic substances, and simultaneously reduce the risk of exposure for a group of workers [24-27].

In recent years, the concept of integrated collective protective equipment has been actively developing. Such systems combine engineering installations, automated monitoring, digital platforms for analysing production risks, and intelligent algorithms for predicting emergencies. Solutions of this kind provide continuous real-time monitoring of the state of the production environment and enable timely measures to prevent hazardous events [28-30].

The international system of occupational safety and health rests on a set of fundamental principles enshrined in the international regulatory instruments of the ILO, the United Nations, and the International Organization for Standardization, as well as in the regulatory documents of the European Union and in the national legislation of the leading industrialized states. The principal purpose of these principles is to prevent occupational injuries and occupational diseases by creating safe working conditions, eliminating production hazards, and introducing modern systems of occupational risk management [31-33].

Table 2 - Comparative characterization of the requirements for collective protective equipment in the event of exposure to chemical factors

Criterion	Republic of Kazakhstan	European Union / Germany	United States
Regulatory framework	Labour Code of the RoK; Rules for the Management of Occupational Risks; sanitary rules and norms; technical regulations.	Directive 98/24/EC; REACH (Regulation (EC) No 1907/2006); in Germany - GefStoffV, TRGS/TRBS.	OSHA: 29 CFR 1910.119 (Process Safety Management), 29 CFR 1910.1200 (Hazard Communication).
Protection priority	Priority of eliminating or reducing risk; use of engineering and collective means of protection to isolate workers from the source of hazard.	Priority of eliminating or substituting the hazardous chemical agent and of collective protective measures ahead of PPE.	Priority of hazard elimination and engineering control; PPE is used against residual risk.
Requirements for CPE	The employer is obliged to provide workers with CPE. When assessing occupational risk, provision is made for isolating workers from the source of the harmful or hazardous factor by engineering and/or collective means of protection.	Sealing and isolation of processes, local exhaust ventilation, systems for removing contaminated air, automation, and technical means of preventing releases are provided for. In Germany, technical measures take priority over organizational measures and PPE.	For processes falling under 1910.119, information on the process equipment must include the ventilation system design, piping and instrumentation diagrams, pressure-relief systems, emergency shut-off systems, sensors, alarms, and interlocks. Equipment must comply with recognized engineering practices.
Enforcement mechanism	Assessment and management of occupational risks; internal production control; state control in the sphere of labour; verification of the conformity of CPE with regulatory requirements.	Risk assessment by the employer, documentation of protective measures, internal production control, and state supervision. In Germany, the effectiveness of technical measures is subject to regular verification.	OSHA inspections, analysis of compliance with the standards, verification of process safety management and hazardous chemicals documentation, and monitoring of working conditions.
Liability for violations	Administrative liability for violation of safety and occupational-health requirements; the employer bears responsibility for failure to ensure safe working conditions and the necessary means of protection.	In Germany - administrative measures, orders to eliminate violations, and the restriction or discontinuation of hazardous work; in defined cases, criminal liability is possible.	OSHA imposes monetary penalties for violations of occupational safety requirements; enhanced penalties are possible for wilful and repeated violations.

The comparison of the regulatory legal acts of the Republic of Kazakhstan, Germany, the European Union, and the United States indicates that modern occupational safety systems addressing exposure to chemical factors share a common orientation toward preventing the effect of hazardous substances by means of risk management and the deployment of necessary collective protective equipment.

In the European Union, the linkage between the assessment of chemical exposure risk and the choice of protective means is enshrined more consistently. The foundational instrument is Directive 98/24/EC, which prescribes elimination or reduction to the lowest possible level of the risk associated with chemical agents. Priority is given to the substitution of a hazardous substance by a less hazardous one. Where substitution is not feasible, the use of technical and collective protective means is provided for. Accordingly, the European approach is oriented toward preventing exposure to chemical substances directly at the source of hazard, whereas personal protective equipment is regarded as supplementary protection [34-36].

The German occupational safety system is founded on the requirements of the Occupational Safety and Health Act (Arbeitsschutzgesetz), the German Ordinance on Hazardous Substances (Gefahrstoffverordnung, GefStoffV), the Technical Rules for Operational Safety (Technische Regeln für Betriebssicherheit, TRBS), and the activities of the German Social Accident Insurance (DGUV). One of the key features of the German model is the mandatory assessment of occupational risks, which the employer is obliged to conduct for every workplace prior to the commencement of production activity. On the basis of the results of the occupational risk assessment (ORA), measures are adopted to eliminate the identified hazards, with priority given to engineering solutions and collective protective equipment. This approach has enabled a substantial reduction in the level of occupational injuries and occupational morbidity [37-40].

At the present time, Germany is one of the world leaders in the use of collective protective equipment. Automated ventilation systems, noise-protection screens, protective enclosures for equipment, local exhausts for harmful substances, interlocking systems for hazardous mechanisms, and the remote control of technological processes are widely employed in industry. Considerable attention is paid to the digital monitoring of the state of the production environment, which enables the timely detection of deviations in safety parameters and the prevention of emergencies [41].

The American OSHA model is distinguished by a high degree of specificity with regard to chemically hazardous technological processes. Standard 29 CFR 1910.119 is aimed at preventing or minimizing the consequences of catastrophic releases of toxic, highly reactive, flammable, or explosive chemical substances. The standard requires the performance of a hazard analysis intended to identify, evaluate, and control the hazard. The American model treats CPE as a set of interrelated engineering barriers directed at preventing the release of a chemical substance, its dispersion, and its effect on workers. Requirements pertaining to the mechanical integrity of equipment, inspections and tests, incident investigation, emergency planning, and periodic audits are likewise of no small importance [42-43].

Analysis of these approaches allows the conclusion that the principal distinction of the foreign models lies in the degree to which collective protective equipment is integrated into the occupational risk management system. In the European Union and Germany, protective measures are formulated on the basis of risk assessment and the application of preventive measures at the design stage, whereas the American model provides detailed requirements for a specific technological process and its engineering systems.

The development of the international system of occupational risk management exerts a substantial influence on the improvement of the legislation of the Republic of Kazakhstan in the field of safety and occupational health. In recent years, the principles of risk-based occupational safety management have been consistently introduced into the national regulatory framework, providing for the transition from a compensatory model of worker protection to a preventive system for anticipating occupational risks. This approach is aligned with contemporary international trends set out in the standards of the ISO 45001:2018 series, the directives of the European Union, the recommendations of the International Labour Organization, and OSHA documents [44].

The foundation of the national regulatory system on occupational safety issues comprises the Labour Code of the Republic of Kazakhstan, the Model Regulation on the Occupational Safety Management System, the Rules for the Management of Occupational Risks, and the Concept of Safe Labour of the Republic of Kazakhstan for 2024–2030. These documents envisage

the phased modernization of the occupational safety system on the basis of occupational risk assessment, the introduction of modern safety-management methods, and the harmonization of national legislation with international requirements [45-48].

One of the most significant directions in the reform of the national occupational safety system is the introduction of a risk-based approach into the procedures for evaluating working conditions. Unlike the traditional model, which was based predominantly on the classification of harmful production factors, the modern system envisages a comprehensive assessment of the probability of hazardous events, the severity of possible consequences, and the effectiveness of existing protective measures. This makes it possible to take managerial decisions on the basis of a quantitative assessment of occupational risks and to select the most effective technical means of worker protection [46].

In international practice, priority in the choice of measures for reducing occupational risks is accorded to the assessment of occupational risks and to collective protective equipment. An analogous principle is being progressively introduced into the legislation of the Republic of Kazakhstan. The national regulatory documents establish the employer's obligation to take measures to eliminate or minimize the effect of hazardous factors of the production environment, using above all engineering solutions, equipment modernization, automation of technological processes, ventilation systems, protective enclosures, and other collective means of protection. Personal protective equipment is regarded as a supplementary level of safety in cases where the use of collective means does not entirely eliminate the occupational risk [47].

It should be noted that, compared with the legislation of foreign countries, the occupational risk management system is at a stage of active development. In most developed countries, occupational risk assessment has long been an obligatory element of the production process and has been integrated into corporate safety management systems. In Kazakhstan, analogous mechanisms are being actively introduced through the implementation of the Concept of Safe Labour for 2024–2030, which envisages expanding the coverage of enterprises by the occupational risk assessment system, improving the methodology for their quantitative assessment, and developing digital tools for monitoring working conditions [46-48].

The digitalization of occupational safety management processes deserves separate consideration. In international practice, intelligent monitoring systems for the production environment, automated control of technological processes, digital platforms for occupational risk management, and artificial-intelligence technologies have gained wide currency. In the Republic of Kazakhstan, these directions have likewise been designated as priorities. The Concept of Safe Labour provides for the creation of a national monitoring system in the sphere of occupational safety, the digitalization of occupational risk assessment results, the improvement of state-control mechanisms, and the introduction of modern information technologies into the occupational safety management system [49-51].

Notwithstanding the considerable progress made in improving the legislation, individual elements of international practice have not yet been fully implemented. In particular, further development is required of the mechanisms for integrating the results of occupational risk assessment into the design of production facilities, the wider use of digital hazard-prediction technologies, the elaboration of unified requirements for selecting collective protective equipment with regard to the level of occupational risk, and the more extensive application of the international standards ISO 45001 and ISO 31000 in the organization of corporate occupational safety management systems [52-54].

Accordingly, the improvement of Kazakhstan's regulation should be directed not only toward expanding the range of collective protective equipment, but also toward establishing a mechanism for its mandatory selection in accordance with the type of chemical factor, the nature of the technological process, the level of exposure, and the degree of occupational risk. Such an approach will make it possible to move from the essentially formal presence of protective means to an assessment of their actual effectiveness and correspondence to the specific chemical risk. For Kazakhstan, it is expedient to strengthen the linkage between the results of the assessment of occupational risks arising from chemical factors and the mandatory selection of collective protective equipment. At the same time, regulatory oversight may be supplemented by criteria for the selection of equipment sealing, local exhaust ventilation, automation and remote control, gas-analytical monitoring, interlocks, alarms, and emergency systems.

Table 3 - Comparative analysis of approaches to the management of occupational risks and the use of CPE

Comparison criterion	European Union / Germany	United States	Kazakhstan
Assessment of occupational risks	Employer's duty to assess risks in relation to work processes and workplaces prior to the commencement of production activity.	Identification and evaluation of hazards.	Gradual introduction of the ORA is under way.
Priority of protective measures	Hierarchy of protective measures: elimination of the hazard; technical and organizational measures; PPE.	Hierarchy of control: elimination; substitution; engineering measures; administrative measures; PPE.	Risk-based approach combining preventive, technical, and organizational measures, CPE, and PPE.
Collective protective equipment	CPE constitutes an important part of technical protection. Protective enclosures, interlocks, isolation, ventilation, automation, and remote control are widely employed.	Engineering measures take priority over administrative ones. It is enshrined in law that engineering and work-practice measures must be the principal means of reducing exposure to chemical substances. Protective enclosures, interlocks, isolation, ventilation, automation, and remote control are used.	Provision is made for the use of engineering and collective protective measures, including ventilation, enclosures, automation, and other technical solutions.
Linkage of risk assessment with engineering design	On the basis of the ORA, the need to introduce engineering solutions is determined prior to the commencement of production activity.	OSHA recommends Prevention through Design (PtD), the design of workplaces, tools, and processes; and, where possible, the selection of equipment, machinery, and materials providing a high level of safety.	The linkage of occupational risk assessment with the design and modernization of production facilities is at a stage of further development.
Digital monitoring	Digital and automated systems are used to monitor the parameters of the production environment and technological processes.	Digital technologies may be used for monitoring, data analysis, and verification of effectiveness.	The digitalization of occupational risk assessment and of occupational safety monitoring is designated as a direction of development.
Overall character of the system	Predominantly preventive, risk-based model.	Preventive, risk-based, founded on the hierarchy of control and on engineering protection.	Transition from the traditional compensatory model to a risk-based system.

The comparative analysis of the approaches to occupational risk management and the use of collective protective equipment in Germany, Kazakhstan, and the United States indicates that all three systems place principal emphasis on the prevention and reduction of occupational risks. At the same time, in Germany and the United States the hierarchy of protective measures is more clearly enshrined, providing for the priority of eliminating and reducing the hazard directly at its source and the use of engineering and collective protective means, while personal protective equipment is regarded as a supplementary, lower tier of protection. In Germany, this principle is directly enshrined in occupational safety legislation, whereas in the United States it is implemented through the OSHA hierarchy of hazard controls. In Kazakhstan, the occupational risk management system likewise envisages the identification and assessment of risks, the elaboration of corrective measures, and monitoring and control, including accounting for the provision of workers with collective and personal means of protection. Nevertheless, for the further improvement of the Kazakhstani approach it is expedient to strengthen the priority of engineering and collective measures,

as well as the linkage of the results of occupational risk assessment with the design and modernization of technological processes and with digital monitoring of the effectiveness of CPE [55-59].

Conclusions. The comparative analysis carried out has shown that collective protective equipment is the priority tier of protection for workers in chemical production, since it makes it possible to act directly upon the source of chemical hazard, to prevent the dispersion of harmful substances, and simultaneously to provide protection for a group of workers.

It has been established that, against a common orientation toward preventing exposure to hazardous substances, the key distinction of the foreign models lies in the depth to which CPE is integrated into the risk management system. In the EU and Germany, protective measures are imperatively embedded at the design stage on the basis of risk assessment, whereas in the United States the regulation is of a more detailed, process-oriented character. The Kazakhstani system is formally close to the international hierarchy of control measures, but requires reinforcement of the priority of engineering solutions over administrative measures and personal protective equipment.

For the improvement of the Kazakhstani occupational risk management system, it is recommended: to reinforce the regulatory linkage of risk assessment procedures with the stages of the design and modernization of production facilities; to introduce a mechanism of mandatory, evidence-based selection of CPE in accordance with the type of chemical risk, the specifics of the process, and the level of exposure; and to supplement the technical regulations with specific effectiveness criteria for systems of sealing, ventilation, automation, gas-analytical monitoring, and emergency response.

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Литература

1. Рахметова А.М., Алшынбекова Г.К., Кульмагамбетова Э.А., Сагиндикова Н.Т., Шилменова А.Т. Өңдеу өнеркәсібі жұмыскерлерінің денсаулық жағдайына өндірістік ортадағы химиялық факторлардың әсері //Вестник Университета Шакарима.- 2026. - №1.-С. 636-646. DOI 10.53360/2788-7995-2026-1(21)-69.
2. Актаева Л.М., Рахметова А.М., Кульмагамбетова Э.А., Алшынбекова Г.К., Шилменова А.Т., Сагиндикова Н.Т., Ташенов А.Ш., Еркінбекова А.Е. Тау-кен саласындағы еңбек жағдайларының жұмыскерлердің денсаулық жағдайына әсерін талдау //Вестник КазУТБ.-2026.-№ 2.-С.560-573. DOI 10.58805/kazutb.v.2.31-1652.
3. Aktayeva, L., Bekmagambetov, A., Yedilbayeva, L., Rakhmetova, A., Daumova, G., Kulmagambetova, E., Sagindykova, N. Impact of green jobs on worker classification and categorization. International Journal of Safety and Security Engineering.-2025.- Vol. 15(9).P. 1861-1872. DOI 10.18280/ijsse.150910.
4. Bekmagambetov, A., Rakhmetova, A., Yedilbayeva, L., Daumova, G., Kulmagambetova, E., Abdrakhmanova, N., Sagindykova, N. (2025). A study on causal relationships between working conditions and occupational diseases: A case study of a phosphorus plant in Kazakhstan. International Journal of Safety and Security Engineering.-2025.-Vol.15(5).-P. 973-985. DOI 10.18280/ijsse.150511.
5. M.A. Yelubay, A.B. Bekmagambetov, E.A. Kulmagambetova, A.M. Rakhmetova, D.T. Tolegenov. Overview of mechanisms for ensuring safe work in chemical production //Vestnik KazUTB.-2025.-№1(26).- C.179-192. DOI 10.58805/kazutb.v.1.26-653.
6. International Labour Organization. Global Strategy on Occupational Safety and Health 2024-30 and plan of action for its implementation. - Geneva: ILO, 2023. URL: https://www.ilo.org/resource/conference-paper/gb/349/global-strategy-occupational-safety-and-health-2024%E2%80%9330-and-plan-action-its Date accessed: 19.05.2026.
7. International Labour Organization. Nearly 3 million people die of work-related accidents and diseases. - Geneva: ILO, 2023. - URL: https://www.ilo.org/resource/news/nearly-3-million-people-die-work-related-accidents-and-diseases Date acessed: 19.05.2026.

8. Federal Public Service Employment, Labour and Social Dialogue. Collective protective equipment (CPE). Brussels: Federal Public Service Employment, Labour and Social Dialogue.- URL:https://employment.belgium.be/en/themes/international/posting/working-conditions-be-respected-case-posting-belgium/well-being-4 Date accessed: 19.05.2026.
9. Rosner D., Markowitz G. A Short History of Occupational Safety and Health in the United States //American Journal of Public Health.-2020.-Vol.110(5).-P.622-628. DOI 10.2105/AJPH.2020.305581.
10. European Agency for Safety and Health at Work. Digitalisation of work [Электронный ресурс].-Bilbao: EU-OSHA.URL: https://osha.europa.eu/en/themes/digitalisation-work- Date accessed: 19.05.2026.
11. Dunn K.H., Echt A., Garcia A. In-Depth Survey Report: Evaluation of Engineering Controls for the Mixing of Flavoring Chemicals at Gold Coast Ingredients, Inc., Commerce, California. - Cincinnati, OH : National Institute for Occupational Safety and Health.- 2008.- 34 p. DOI 10.26616/NIOSHEPHB32211a.
12. Hahn N. Schutzmaßnahmen beim Umgang mit Styrol: Zusammenfassung der Vorträge anlässlich des BGIA-Seminars G3 - Technische Schutzmaßnahmen am 13./14. September 2005 in Dresden.-Sankt Augustin: BGIA, 2006.- 117p.-BGIA-Report4/2006. ISBN 3-88383-704-0.
13. Havet N., Penot A. Collective Protection Measures for Occupational Exposure to Carcinogenic Chemicals in France: The Links between Regulations on Chemicals and Effective Implementation ;// International Journal of Environmental Research and Public Health.- 2022.- Vol. 19(14). - Article 8553. DOI 10.3390/ijerph19148553.
14. Rosen P. H., Heinold E., Fries-Tersch E., Wischniewski S. Advanced robotics and automation: implications for occupational safety and health. Luxembourg: Publications Office of the European Union, 2022.- 45 p. DOI 10.2802/789276.
15. European Agency for Safety and Health at Work. Directive 89/391/EEC- OSH “Framework Directive”.- Bilbao: EU-OSHA.-2021.- URL: https://osha.europa.eu/en/legislation/directives/the-osh-framework-directive/1 Date accessed: 19.05.2026.
16. National Institute for Occupational Safety and Health. Hierarchy of Controls - Atlanta: Centers for Disease Control and Prevention, 2024.- URL: https://www.cdc.gov/niosh/hierarchy-of-controls/index.html.- Date accessed: 19.05.2026.
17. ГОСТ 12.4.011–89. Система стандартов безопасности труда. Средства защиты работающих. Общие требования и классификация. - М: Издательство стандартов, 1989. URL: https://prg.kz/document/?doc_id=30039424&pos=2;268 Дата обращения: 21.05.2026.
18. ГОСТ 12.4.125-83. Система стандартов безопасности труда. Средства коллективной защиты работающих от воздействия механических факторов. Классификация. - М.: Издательство стандартов, 1983. URL: https://prg.kz/document/?doc_id=30052139-Дата обращения: 21.06.2026.
19. Ajslev J. Z. N., Møller J. L., Andersen M. F., Pirzadeh P., Lingard H. The Hierarchy of Controls as an Approach to Visualize the Impact of Occupational Safety and Health Coordination // International Journal of Environmental Research and Public Health. 2022. Vol. 19(5): 2731. DOI 10.3390/ijerph19052731.
20. Dyreborg J., Lipscomb H. J., Nielsen K. et.all. Safety interventions for the prevention of accidents at work: A systematic review // Campbell Systematic Reviews. - 2022.- Vol. 18(2).- 187 p. DOI 10.1002/cl2.1234.
21. Amyotte P. R., MacDonald D. K., Khan F. I. An analysis of CSB investigation reports concerning the hierarchy of controls // Process Safety Progress. - 2011.- Vol. 30(3). - P.261-265. DOI 10.1002/prs.10461.
22. Federal Public Service Employment, Labour and Social Dialogue. Collective protective equipment (CPE). Brussels: Federal Public Service Employment, Labour and Social Dialogue. URL:https://employment.belgium.be/en/themes/international/posting/working-conditions-berespected-case-posting-belgium/well-being-4.- Date accessed: 21.05.2026.
23. European Agency for Safety and Health at Work. Smart digital systems for better safety and health at work. Bilbao: EU-OSHA, 2025.-Healthy Workplaces. URL: https://healthy-workplaces.osha.europa.eu/en/publications/smart-digital-systems-better-safety-and-health-work Date accessed: 21.06.2026.
24. European Agency for Safety and Health at Work. Smart digital monitoring systems for occupational safety and health: uses and challenges. - Luxembourg: Publications Office of the European Union.-2022. DOI 10.2802/25469.
25. Edoardo Ales ILO Convention 155 Occupational Safety and Health Convention, 1981 (No. 155): Article-by-Article Commentary// In book: International and European Labour Law. (pp.1392-1413) DOI 10.5771/9783845266190-1408.

26. International Labour Organization. A safe and healthy working environment is a fundamental principle and right at work.- Geneva: ILO, 2022.- URL: https://www.ilo.org/topics-and-sectors/safety-and-health-work/safe-and-healthy-working-environment-fundamental-principle-and-right-work Date accessed: 21.06.2026.
27. ISO 45001:2018. Occupational health and safety management systems - Requirements with guidance for use. Geneva: International Organization for Standardization, 2018. - 41 p. -URL: https://www.iso.org/standard/63787.html - Date accessed: 19.06.2026.
28. Germany. Arbeitsschutzgesetz (ArbSchG). §5 Beurteilung der Arbeitsbedingungen. Berlin: Bundesministerium der Justiz.- URL: https://www.gesetze-im-internet.de/arbschg/__5.html Date accessed: 19.08.2026.
29. Deutsche Gesetzliche Unfallversicherung. Risk assessment. - Berlin: DGUV. URL: https://www.dguv.de/en/prevention/topics-a-z/risk-assessment/index.jsp- Date accessed: 19.06.2026.
30. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin. Seven Steps for Risk Assessment.- Dortmund: BAuA. - URL: https://www.baua.de/EN/Topics/Work-design/Risk-assessment/Handbook/Basic-knowledge/Seven-steps-for-risk-assessment/Seven-steps-for-risk-assessment_dossier Date accessed: 21.06.2026.
31. International Covenant on Economic, Social and Cultural Rights: adopted by General Assembly resolution 2200A (XXI) of 16 December 1966, entry into force 3 January 1976, in accordance with article 27. New York: United Nations.URL: https://www.ohchr.org/Documents/ProfessionalInterest/cescr.pdf- Date accessed: 19.06.2026.
32. Committee on Economic, Social and Cultural Rights. General Comment No. 23 (2016) on the right to just and favourable conditions of work (article 7 of the International Covenant on Economic, Social and Cultural Rights). - Geneva: United Nations, 2016. URL: https://docstore.ohchr.org/SelfServices/FilesHandler.ashx?enc=HI2WCrNprXdb93hp8EpBQSD6WO%2BYesFqEE0JfrJby0t9VYUTpZLRSlSaIpG%2BacqIvC9slPR3ZWPdNLwq0seqqg%3D%3D Date accessed: 22.05.2026.
33. International Labour Organization. Controlling the Risks.-Geneva: ILO. URL: https://www.ilo.org/topics-and-sectors/occupational-safety-and-health-guide-labour-inspectors-and-other/how-can-occupational-safety-and-health-be-managed/controlling-risks- Date accessed: 22.05.2026.
34. Germany. Arbeitsschutzgesetz (ArbSchG). Gesetz über die Durchführung von Maßnahmen des Arbeitsschutzes zur Verbesserung der Sicherheit und des Gesundheitsschutzes der Beschäftigten bei der Arbeit.-Berlin: Bundesministerium der Justiz. URL: https://www.gesetze-im-internet.de/arbschg/ - Date accessed: 22.05.2026.
35. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin. Technische Regeln für Betriebssicherheit (TRBS). - Dortmund: BAuA. URL: https://www.baua.de/DE/Angebote/Regelwerk/TRBS/TRBS Date accessed: 22.05.2026.
36. Deutsche Gesetzliche Unfallversicherung. Gefährdungsbeurteilung - Berlin: DGUV. URL: https://www.dguv.de/de/praevention/themen-a-z/gefaehrdungsbeurteilung/index.jsp Date accessed: 22.05.2026.
37. Об утверждении Правил управления профессиональными рисками: приказ Министра труда и социальной защиты населения Республики Казахстан от 11 сентября 2020 года №363, в редакции приказа Министра труда и социальной защиты населения Республики Казахстан от 28 мая 2026 года №211. URL: https://adilet.zan.kz/rus/docs/V2000021197 -Дата обращения: 19.06.2026.
38. ISO 45001:2018. Occupational health and safety management systems - Requirements with guidance for use. Geneva: International Organization for Standardization, 2018. URL: https://www.iso.org/standard/63787.html- Date accessed: 22.05.2026.
39. International Labour Organization. Guidelines on occupational safety and health management systems, ILO-OSH 2001. Geneva: ILO, 2001. URL: https://www.ilo.org/publications/guidelines-occupational-safety-and-health-management-systems-ilo-osh-2001 Date accessed: 22.05.2026.
40. Трудовой кодекс Республики Казахстан: Кодекс Республики Казахстан от 23 ноября 2015 года № 414-V ЗРК. URL: https://adilet.zan.kz/rus/docs/K1500000414 -Дата обращения: 19.06.2026.
41. Об утверждении Типового положения о системе управления охраной труда: приказ Министра труда и социальной защиты населения Республики Казахстан от 27 августа 2020 года № 340. URL: https://adilet.zan.kz/rus/docs/V2000021140 Дата обращения: 19.06.2026.
42. Об утверждении Концепции безопасного труда Республики Казахстан на 2024–2030 годы URL: постановление Правительства Республики Казахстан от 28 декабря 2023 года №1182. URL: https://adilet.zan.kz/rus/docs/P2300001182 Дата обращения: 19.06.2026.

43. International Labour Organization. A 5 step guide for employers, workers and their representatives on conducting workplace risk assessments.-Geneva: ILO, 2013. URL: https://labordoc.ilo.org/discovery/fulldisplay/alma994843073402676/41ILO_INST:41ILO_V2 Date accessed: 22.05.2026.
44. Ellenbecker M. J. Engineering controls as an intervention to reduce worker exposure //American Journal of Industrial Medicine. −1996. Vol. 29(4). -P. 303–307. DOI 10.1002/(SICI)1097-0274(199604)29:43.0.CO;2-P.
45. Gangolells M., Casals M., Forcada N., Roca X., Fuertes A. Mitigating construction safety risks using prevention through design \//Journal of Safety Research. - 2010. - Vol. 41(2). - P. 107-122. DOI 10.1016/j.jsr.2009.10.007.
46. Schulte P. A., Rinehart R., Okun A., Geraci C. L., Heidel D. S. National Prevention through Design (PtD) Initiative //Journal of Safety Research. - 2008. - Vol.39(2). - P. 115-121. DOI 10.1016/j.jsr.2008.02.021.
47. Richter E. D., Kretzmer D. Prevention through pre-review in occupational health and safety //American Journal of Public Health.-1980.-Vol.70(2).-P.157-161. DOI 10.2105/AJPH.70.2.157.
48. Ledda A., Berardi S., Bemporad E. A review of collective protective measures for workers in contaminated sites //WIT Transactions on Information and Communication Technologies. - 2014. - Vol. 47. - P. 307-317. DOI 10.2495/RISK140261.
49. European Agency for Safety and Health at Work. Artificial intelligence for worker management: implications for occupational safety and health. Luxembourg: Publications Office of the European Union. URL: https://osha.europa.eu/en/publications/artificial-intelligence-worker-management-implications-occupational-safety-and-health Date accessed: 22.05.2026.
50. Mansi A., Boccuni F., Iavicoli S. Nanomaterials as a new opportunity for protecting workers from biological risk //Industrial Health.-2019.-Vol.57(6).-P.668-675. DOI 10.2486/indhealth.2018-0197.
51. Hardison D., Hallowell M. Construction hazard prevention through design: Review of perspectives, evidence, and future objective research agenda // Safety Science.- 2019.- Vol. 120. - P.517-526. DOI 10.1016/j.ssci.2019.08.001.
52. Jiang L., Zhang J., Wong Y. D. Digital technology in occupational health of manufacturing industries: a systematic literature review \//Discover Applied Sciences. - 2024. -Vol. 6:631. DOI 10.1007/s42452-024-06349-4
53. Martínez-Aires M. D., López-Alonso M., de la Hoz-Torres M. L., Aguilar-Aguilera A., Arezes P. Occupational risk prevention in the European Union construction sector: 30 Years since the publication of the Directive// Safety Science.-2024.-Vol.177:106593. DOI 10.1016/j.ssci.2024.106593.
54. International Organization for Standardization. ISO 31000:2018. Risk management - Guidelines.-Geneva:ISO, 2018. URL: https://www.iso.org/standard/65694.html Date accessed: 19.06.2026.
55. Dewlaney K. S., Hallowell M. Prevention through design and construction safety management strategies for high performance sustainable building construction //Construction Management and Economics.-2012.-Vol.30(2). DOI 10.1080/01446193.2011.654232.
56. Weinstein M., Susi P., Goldberg M. The power of local action in occupational health: the adoption of local exhaust ventilation in the Chicago tuckpointing trade // International Journal of Occupational and Environmental Health.-2016.-Vol.22(2)-P.142-150. DOI 10.1080/10773525.2016.1187476.
57. Lee T., Soo J.-C., LeBouf R. F., Burns D., Schwegler-Berry D., Kashon M., Bowers J., Harper M. Surgical smoke control with local exhaust ventilation: Experimental study // Journal of Occupational and Environmental Hygiene. −2018.- Vol. 15(4). -P.341-350. DOI 10.1080/15459624.2017.1422082.
58. Occupational Safety and Health Administration (OSHA). Chemical Hazards and Toxic Substances: Controlling Exposure. U.S. Department of Labor. URL: https://www.osha.gov/chemical-hazards/controlling-exposure Date accessed: 22.05.2026.
59. National Institute for Occupational Safety and Health. Current Strategies for Engineering Controls in Nanomaterial Production and Downstream Handling Processes [Электронный ресурс].-DHHS (NIOSH) Publication No.2014-102.-URL: https://www.cdc.gov/niosh/docs/2014-102/ - Date accessed: 22.05.2026.

References

1. Rahmetova A.M., Alshynbekova G.K., Kul'magambetova Je.A., Sagindikova N.T., Shilmenova A.T. Өңdeu өnerkəsibi zhұmyskerlerinің densaulyқ zharғdajyna өndiristik ortadarғy himijalyқ faktorlardyң əseri \//Vestnik Universiteta Shakarima.- 2026. - №1.-S. 636-646. DOI 10.53360/2788-7995-2026-1(21)-69. [in Kazakh]
2. Aktaeva L.M., Rahmetova A.M., Kul'magambetova Je.A., Alshynbekova G.K., Shilmenova A.T., Sagindikova N.T., Tashenov A.Sh., Erkinbekova A.E. Tau-ken salasyndarғy eңbek zharғdajlarynyң zhұmyskerlerdің densaulyқ zharғdajyna əserin taldau //Vestnik KazUTB.-2026.-№2.-S.560-573. DOI 10.58805/kazutb.v.2.31-1652. [in Kazakh]
3. Aktayeva, L., Bekmagambetov, A., Yedilbayeva, L., Rakhmetova, A., Daumova, G., Kulmagambetova, E., Sagindykova, N. Impact of green jobs on worker classification and categorization. International Journal of Safety and Security Engineering.-2025.- Vol. 15(9).P. 1861-1872. DOI 10.18280/ijsse.150910.
4. Bekmagambetov, A., Rakhmetova, A., Yedilbayeva, L., Daumova, G., Kulmagambetova, E., Abdrakhmanova, N., Sagindykova, N. (2025). A study on causal relationships between working conditions and occupational diseases: A case study of a phosphorus plant in Kazakhstan. International Journal of Safety and Security Engineering.-2025.-Vol.15(5).-P. 973-985. DOI 10.18280/ijsse.150511.
5. M.A. Yelubay, A.B. Bekmagambetov, E.A. Kulmagambetova, A.M. Rakhmetova, D.T. Tolegenov. Overview of mechanisms for ensuring safe work in chemical production //Vestnik KazUTB.-2025.-№1(26).- C.179-192. DOI 10.58805/kazutb.v.1.26-653
6. International Labour Organization. Global Strategy on Occupational Safety and Health 2024-30 and plan of action for its implementation. - Geneva: ILO, 2023. URL: https://www.ilo.org/resource/conference-paper/gb/349/global-strategy-occupational-safety-and-health-2024%E2%80%9330-and-plan-action-its Date accessed: 19.05.2026.
7. International Labour Organization. Nearly 3 million people die of work-related accidents and diseases. - Geneva: ILO, 2023. - URL: https://www.ilo.org/resource/news/nearly-3-million-people-die-work-related-accidents-and-diseases Date acessed: 19.05.2026.
8. Federal Public Service Employment, Labour and Social Dialogue. Collective protective equipment (CPE). Brussels: Federal Public Service Employment, Labour and Social Dialogue.- URL:https://employment.belgium.be/en/themes/international/posting/working-conditions-be-respected-case-posting-belgium/well-being-4 Date accessed: 19.05.2026.
9. Rosner D., Markowitz G. A Short History of Occupational Safety and Health in the United States //American Journal of Public Health.-2020.-Vol.110(5). -P.622-628. DOI 10.2105/AJPH.2020.305581.
10. European Agency for Safety and Health at Work. Digitalisation of work [Электронный ресурс].-Bilbao: EU-OSHA.URL: https://osha.europa.eu/en/themes/digitalisation-work- Date accessed: 19.05.2026.
11. Dunn K.H., Echt A., Garcia A. In-Depth Survey Report: Evaluation of Engineering Controls for the Mixing of Flavoring Chemicals at Gold Coast Ingredients, Inc., Commerce, California. - Cincinnati, OH : National Institute for Occupational Safety and Health.- 2008.- 34 p. DOI 10.26616/NIOSHEPHB32211a.
12. H«ahn N. Schutzmaßnahmen beim Umgang mit Styrol: Zusammenfassung der Vorträge anlässlich des BGIA-Seminars G3 - Technische Schutzmaßnahmen am 13./14. September 2005 in Dresden.-Sankt Augustin: BGIA, 2006.- 117p.-BGIA-Report4/2006. ISBN 3-88383-704-0.
13. Havet N., Penot A. Collective Protection Measures for Occupational Exposure to Carcinogenic Chemicals in France: The Links between Regulations on Chemicals and Effective Implementation ;// International Journal of Environmental Research and Public Health.- 2022.- Vol. 19(14):8553.- DOI 10.3390/ijerph19148553.
14. Rosen P. H., Heinold E., Fries-Tersch E., Wischniewski S. Advanced robotics and automation: implications for occupational safety and health. Luxembourg: Publications Office of the European Union, 2022.- 45 p. DOI 10.2802/789276.
15. European Agency for Safety and Health at Work. Directive 89/391/EEC- OSH “Framework Directive”.- Bilbao: EU-OSHA.-2021.- URL: https://osha.europa.eu/en/legislation/directives/the-osh-framework-directive/1 Date accessed: 19.05.2026.
16. National Institute for Occupational Safety and Health. Hierarchy of Controls - Atlanta: Centers for Disease Control and Prevention, 2024.- URL: https://www.cdc.gov/niosh/hierarchy-of-controls/index.html.- Date accessed: 19.05.2026.

17. GOST 12.4.011–89. Sistema standartov bezopasnosti truda. Sredstva zashhity rabotajushhih. Obshhie trebovanija i klassifikacija. - M: Izdatel'stvo standartov, 1989. URL: https://prg.kz/document/?doc_id=30039424&pos=2;268 -Data obrashhenija: 21.05.2026.[in Russian]
18. GOST 12.4.125-83. Sistema standartov bezopasnosti truda. Sredstva kollektivnoj zashhity rabotajushhih ot vozdejstvija mehanicheskih faktorov. Klassifikacija. - M.: Izdatel'stvo standartov, 1983. URL: https://prg.kz/document/?doc_id=30052139-Data obrashhenija: 21.06.2026. [in Russian]
19. Ajslev J. Z. N., Møller J. L., Andersen M. F., Pirzadeh P., Lingard H. The Hierarchy of Controls as an Approach to Visualize the Impact of Occupational Safety and Health Coordination // International Journal of Environmental Research and Public Health. 2022. Vol. 19(5): 2731. DOI 10.3390/ijerph19052731.
20. Dyreborg J., Lipscomb H. J., Nielsen K. et.all. Safety interventions for the prevention of accidents at work: A systematic review // Campbell Systematic Reviews. - 2022.- Vol. 18(2).- 187 p. DOI 10.1002/cl2.1234.
21. Amyotte P. R., MacDonald D. K., Khan F. I. An analysis of CSB investigation reports concerning the hierarchy of controls // Process Safety Progress. - 2011.- Vol. 30(3). - P.261-265. DOI 10.1002/prs.10461.
22. Federal Public Service Employment, Labour and Social Dialogue. Collective protective equipment (CPE). Brussels: Federal Public Service Employment, Labour and Social Dialogue. URL:https://employment.belgium.be/en/themes/international/posting/working-conditions-berespected-case-posting-belgium/well-being-4.- Date accessed: 21.05.2026.
23. European Agency for Safety and Health at Work. Smart digital systems for better safety and health at work. Bilbao: EU-OSHA, 2025.-Healthy Workplaces. URL: https://healthy-workplaces.osha.europa.eu/en/publications/smart-digital-systems-better-safety-and-health-work Date accessed: 21.06.2026.
24. European Agency for Safety and Health at Work. Smart digital monitoring systems for occupational safety and health: uses and challenges. - Luxembourg: Publications Office of the European Union.-2022. DOI 10.2802/25469.
25. Edoardo Ales ILO Convention 155 Occupational Safety and Health Convention, 1981 (No. 155): Article-by-Article Commentary// In book: International and European Labour Law. (pp.1392-1413) DOI 10.5771/9783845266190-1408.
26. International Labour Organization. A safe and healthy working environment is a fundamental principle and right at work.- Geneva: ILO, 2022.- URL: https://www.ilo.org/topics-and-sectors/safety-and-health-work/safe-and-healthy-working-environment-fundamental-principle-and-right-work Date accessed: 21.06.2026.
27. ISO 45001:2018. Occupational health and safety management systems - Requirements with guidance for use. Geneva: International Organization for Standardization, 2018. - 41 p. -URL: https://www.iso.org/standard/63787.html - Date accessed: 19.06.2026.
28. Germany. Arbeitsschutzgesetz (ArbSchG). §5 Beurteilung der Arbeitsbedingungen. Berlin: Bundesministerium der Justiz.- URL: https://www.gesetze-im-internet.de/arbschg/__5.html Date accessed: 19.08.2026.
29. Deutsche Gesetzliche Unfallversicherung. Risk assessment. - Berlin: DGUV. URL: https://www.dguv.de/en/prevention/topics-a-z/risk-assessment/index.jsp- Date accessed: 19.06.2026.
30. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin. Seven Steps for Risk Assessment.- Dortmund: BAuA. - URL: https://www.baua.de/EN/Topics/Work-design/Risk-assessment/Handbook/Basic-knowledge/Seven-steps-for-risk-assessment/Seven-steps-for-risk-assessment_dossier Date accessed: 21.06.2026.
31. International Covenant on Economic, Social and Cultural Rights: adopted by General Assembly resolution 2200A (XXI) of 16 December 1966, entry into force 3 January 1976, in accordance with article 27. New York: United Nations.URL: https://www.ohchr.org/Documents/ProfessionalInterest/cescr.pdf- Date accessed: 19.06.2026.
32. Committee on Economic, Social and Cultural Rights. General Comment No. 23 (2016) on the right to just and favourable conditions of work (article 7 of the International Covenant on Economic, Social and Cultural Rights). - Geneva: United Nations, 2016. URL: https://docstore.ohchr.org/SelfServices/FilesHandler.ashx?enc=HI2WCrNprXdb93hp8EpBQSD6WO%2BYesFqEE0JfrJby0t9VYUTpZLRSlSaIpG%2BacqIvC9slPR3ZWPdNLwq0seqqg%3D%3D Date accessed: 22.05.2026.
33. International Labour Organization. Controlling the Risks.-Geneva: ILO. URL: https://www.ilo.org/topics-and-sectors/occupational-safety-and-health-guide-labour-inspectors-and-other/how-can-occupational-safety-and-health-be-managed/controlling-risks- Date accessed: 22.05.2026.

34. Germany. Arbeitsschutzgesetz (ArbSchG). Gesetz über die Durchführung von Maßnahmen des Arbeitsschutzes zur Verbesserung der Sicherheit und des Gesundheitsschutzes der Beschäftigten bei der Arbeit.-Berlin: Bundesministerium der Justiz. URL: https://www.gesetze-im-internet.de/arbschg/ - Date accessed: 22.05.2026.
35. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin. Technische Regeln für Betriebssicherheit (TRBS). - Dortmund: BAuA. URL: https://www.baua.de/DE/Angebote/Regelwerk/TRBS/TRBS Date accessed: 22.05.2026.
36. Deutsche Gesetzliche Unfallversicherung. Gefährdungsbeurteilung - Berlin: DGUV. URL: https://www.dguv.de/de/praevention/themen-a-z/gefaehrdungsbeurteilung/index.jsp Date accessed: 22.05.2026.
37. Ob utverzhdenii Pravil upravlenija professional'nymi riskami: prikaz Ministra truda i social'noj zashhity naselenija Respubliki Kazahstan ot 11 sentjabrja 2020 goda №363, v redakcii prikaza Ministra truda i social'noj zashhity naselenija Respubliki Kazahstan ot 28 maja 2026 goda №211. URL: https://adilet.zan.kz/rus/docs/V2000021197 -Data obrashhenija: 19.06.2026. [in Russian]
38. ISO 45001:2018. Occupational health and safety management systems - Requirements with guidance for use. Geneva: International Organization for Standardization, 2018. URL: https://www.iso.org/standard/63787.html- Date accessed: 22.05.2026.
39. International Labour Organization. Guidelines on occupational safety and health management systems, ILO-OSH 2001. Geneva: ILO, 2001. URL: https://www.ilo.org/publications/guidelines-occupational-safety-and-health-management-systems-ilo-osh-2001 Date accessed: 22.05.2026.
40. Trudovoj kodeks Respubliki Kazahstan: Kodeks Respubliki Kazahstan ot 23 nojabrja 2015 goda № 414-V ZRK. URL: https://adilet.zan.kz/rus/docs/K1500000414 - -Data obrashhenija: 19.06.2026. [in Russian]
41. Ob utverzhdenii Tipovogo polozhenija o sisteme upravlenija ohranoj truda: prikaz Ministra truda i social'noj zashhity naselenija Respubliki Kazahstan ot 27 avgusta 2020 goda № 340. URL: https://adilet.zan.kz/rus/docs/V2000021140 -Data obrashhenija: 19.06.2026. [in Russian]
42. Ob utverzhdenii Koncepcii bezopasnogo truda Respubliki Kazahstan na 2024–2030 gody URL: postanovlenie Pravitel'stva Respubliki Kazahstan ot 28 dekabrja 2023 goda №1182. URL: https://adilet.zan.kz/rus/docs/P2300001182 - Data obrashhenija: 19.06.2026. [in Russian]
43. International Labour Organization. A 5 step guide for employers, workers and their representatives on conducting workplace risk assessments.-Geneva: ILO, 2013. URL: https://labordoc.ilo.org/discovery/fulldisplay/alma994843073402676/41ILO_INST:41ILO_V2 Date accessed: 22.05.2026.
44. Ellenbecker M. J. Engineering controls as an intervention to reduce worker exposure //American Journal of Industrial Medicine. −1996. Vol. 29(4).-P.303–307. DOI 10.1002/(SICI)1097-0274(199604)29:43.0.CO;2-P..
45. Gangolells M., Casals M., Forcada N., Roca X., Fuertes A. Mitigating construction safety risks using prevention through design \//Journal of Safety Research. - 2010. - Vol. 41(2). - P. 107-122. DOI 10.1016/j.jsr.2009.10.007.
46. Schulte P. A., Rinehart R., Okun A., Geraci C. L., Heidel D. S. National Prevention through Design (PtD) Initiative //Journal of Safety Research. - 2008.- Vol.39(2)- P.115-121. DOI 10.1016/j.jsr.2008.02.021.
47. Richter E. D., Kretzmer D. Prevention through pre-review in occupational health and safety //American Journal of Public Health.-1980.-Vol.70(2).-P.157–161. DOI 10.2105/AJPH.70.2.157.
48. Ledda A., Berardi S., Bemporad E. A review of collective protective measures for workers in contaminated sites //WIT Transactions on Information and Communication Technologies. – 2014. -Vol. 47. - P. 307-317. DOI 10.2495/RISK140261.
49. European Agency for Safety and Health at Work. Artificial intelligence for worker management: implications for occupational safety and health. Luxembourg: Publications Office of the European Union. URL: https://osha.europa.eu/en/publications/artificial-intelligence-worker-management-implications-occupational-safety-and-health Date accessed: 22.05.2026.
50. Mansi A., Boccuni F., Iavicoli S. Nanomaterials as a new opportunity for protecting workers from biological risk//Industrial Health. −2019.-Vol.57(6).-P.668–675. DOI 10.2486/indhealth.2018-0197.
51. Hardison D., Hallowell M. Construction hazard prevention through design: Review of perspectives, evidence, and future objective research agenda // Safety Science.- 2019.- Vol. 120. - P.517-526.-DOI 10.1016/j.ssci.2019.08.001.

52. Jiang L., Zhang J., Wong Y. D. Digital technology in occupational health of manufacturing industries: a systematic literature review \//Discover Applied Sciences. - 2024. -Vol. 6:631. DOI 10.1007/s42452-024-06349-4
53. Martínez-Aires M. D., López-Alonso M., de la Hoz-Torres M. L., Aguilar-Aguilera A., Arezes P. Occupational risk prevention in the European Union construction sector: 30 Years since the publication of the Directive// Safety Science.-2024.-Vol.177:106593. DOI 10.1016/j.ssci.2024.106593
54. International Organization for Standardization. ISO 31000:2018. Risk management - Guidelines.-Geneva:ISO, 2018. URL: https://www.iso.org/standard/65694.html Date accessed: 19.06.2026.
55. Dewlaney K. S., Hallowell M. Prevention through design and construction safety management strategies for high performance sustainable building construction //Construction Management and Economics.-2012.-Vol.30(2). DOI 10.1080/01446193.2011.654232.
56. Weinstein M., Susi P., Goldberg M. The power of local action in occupational health: the adoption of local exhaust ventilation in the Chicago tuckpointing trade // International Journal of Occupational and Environmental Health.-2016.-Vol.22(2)-P.142-150. DOI 10.1080/10773525.2016.1187476.
57. Lee T., Soo J.-C., LeBouf R. F., Burns D., Schwegler-Berry D., Kashon M., Bowers J., Harper M. Surgical smoke control with local exhaust ventilation: Experimental study // Journal of Occupational and Environmental Hygiene. −2018.- Vol. 15(4). -P.341-350. DOI 10.1080/15459624.2017.1422082.
58. Occupational Safety and Health Administration (OSHA). Chemical Hazards and Toxic Substances: Controlling Exposure. U.S. Department of Labor. URL: https://www.osha.gov/chemical-hazards/controlling-exposure Date accessed: 22.05.2026.
59. National Institute for Occupational Safety and Health. Current Strategies for Engineering Controls in Nanomaterial Production and Downstream Handling Processes [Электронный ресурс].-DHHS (NIOSH) Publication No.2014–102.-URL: https://www.cdc.gov/niosh/docs/2014-102/ - Date accessed: 22.05.2026.

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