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SAFETY ENGINEERING FOR WIND TURBINE HEIGHT OPERATIONS: A CRITICAL REVIEW OF ISO/OSHA/EN STANDARDS

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The article examines the main standards that apply to high-altitude work in the wind energy industry. Such documents are necessary to regulate and ensure safety at all stages of the life cycle of ”green” energy production, with special attention to be paid to the most hazardous areas of activity, including high-altitude work. Based on this, a critical analysis of the requirements and standards in the selected countries is carried out, the standards used and the percentage of uncountable cases in the process of high-altitude work at stations are compared. At the same time, each country adheres to the requirements of uniform international standards, but, if necessary, adopts its own requirements, specifically for certain types of stations, types of work, etc. In conclusion, a number of problematic aspects are put forward, the solution of which will contribute to increasing the level of safety at wind stations.

Keywords: wind energy, green energy, wind power plants, high-altitude work, standards, safety, labor protection, injuries.

ЖЕЛ ТУРБИНАЛАРЫНДАҒЫ ТЕХНИКАЛЫҚ ЖҰМЫСТАРДЫҢ ҚАУІПСІЗДІГІ: ISO/OSHA/EN СТАНДАРТТАРЫН ТАЛДАУ

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Мақалада жел энергетикасы саласындағы биіктік жұмыстарына қолданылатын негізгі стандарттар қаралады. Мұндай құжаттар «жасыл» энергия өндірудің өмірлік циклінің барлық кезеңдерінде қауіпсіздікті реттеу және қамтамасыз ету үшін қажет, бұл ретте қызметтің неғұрлым қауіпті түрлеріне, оның ішінде биіктік жұмыстарына ерекше назар аударылады. Осы негізде таңдалған елдерде талаптар мен стандарттарға сыни талдау жүргізіледі, пайдаланылатын стандарттар салыстырылады және станциялардағы биіктік жұмыстары процесінде есептеуге жатпайтын жағдайлар пайызы салыстырылады. Бұл ретте әрбір ел бірыңғай халықаралық стандарттардың талаптарын ұстанады, бірақ қажет болған кезде арнайы станциялардың белгілі бір типтері, жұмыс түрлері және т.б. үшін өзінің жеке талаптарын қабылдайды. Қорытындысында жел станцияларындағы қауіпсіздік деңгейін арттыруға ықпал ететін бірқатар проблемалық аспектілер алға тартылады.

Түйін сөздер: жел энергиясы, жасыл энергия, жел электр станциялары, биіктік жұмыстары, стандарттар, қауіпсіздік, еңбекті қорғау, жарақаттар.

БЕЗОПАСНОСТЬ ТЕХНИЧЕСКИХ РАБОТ НА ВЕТРОВЫХ ТУРБИНАХ: КРИТИЧЕСКИЙ АНАЛИЗ СТАНДАРТОВ ISO/OSHA/EN

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В статье рассматриваются основные стандарты, применимые к высотным работам в ветроэнергетической отрасли. Такие документы необходимы для регулирования и обеспечения безопасности на всех этапах жизненного цикла производства «зеленой» энергии, при этом особое внимание уделяется наиболее опасным видам деятельности, в том числе высотным работам. На этом основании проводится критический анализ требований и стандартов в выбранных странах, сравниваются используемые стандарты и процент не поддающихся подсчету случаев в процессе высотных работ на станциях. При этом каждая страна придерживается требований единых международных стандартов, но при необходимости принимает свои собственные требования, специально для определенных типов станций, видов работ и т. д. В заключение выдвигается ряд проблемных аспектов, решение которых будет способствовать повышению уровня безопасности на ветровых станциях.

Ключевые слова: ветровая энергия, зеленая энергия, ветровые электростанции, высотные работы, стандарты, безопасность, охрана труда, травмы.

Introduction. The popularity of using wind turbines is growing every year, this is due to the fact that wind energy has become one of the fundamental alternatives in energy production. Wind energy does not harm the environment, its production does not emit greenhouse gases and complies with the principles of the ”green” economy, which all developing countries of the world strive to comply with. Thus, the government of many countries is currently moving away from the use of coal, oil, nuclear fuel and switching to the use of new, clean types of energy [1]. In this regard, there is a significant increase in the popularity of wind energy. Every year, the number of wind stations around the globe increases, their combined growth rate per year is about 11.6%.

At the same time, this growth is due to a number of factors, mainly the availability of financial and human resources that are used in the design and operation of installations, the achievements of scientific and technological progress, legislative support, as well as public assistance and assistance of numerous companies. However, with the development of a new industry, more precise standardization is required, as well as the development of new standards and requirements for both equipment and workers themselves. In the event of inaccuracies in these documents, violations or non-compliance with standards, some problems may arise.

With the increase in the number of wind power plants, the number of workers on them also increases, that is, the primary task should be labor protection and their health [2]. The duties and functions performed by workers at wind energy facilities are usually unique, this is due to the fact that in other industries there is no installation, assembly and maintenance of wind turbines [3]. The working environment is also unique, which provokes possible difficulties in the field of labor protection. Innovative work processes may contain new hazards that employees and administrative personnel must provide for and enshrine in the rules of conduct, as well as in the relevant documents (standards).

Wind energy is a new, modern direction in all countries, new workers may not fully understand what dangers await them when performing their duties. In addition, the technology in this area is developing quite rapidly, which can lead to a shortage of qualified personnel, and inexperienced workers create a great danger for themselves if they have not been trained and therefore can expose themselves to threats and violate safety installations.

Despite the fact that wind energy is considered quite useful for the environment, its production itself is not always useful and safe for workers. Often, at wind farms, employees can encounter dangers that ultimately lead to negative or fatal

consequences. In this regard, the study and critical analysis of safety standards in this area is very relevant, since it is necessary to point out existing problem areas and maintain a high level of labor protection. Workplaces in this area must meet all safety requirements and not have a negative impact on the health of workers.

Daily, in order to reduce the possibility of negative and dangerous phenomena on personnel working at wind farms, their maintenance and inspection are carried out. It is organized under the safest conditions, since almost all wind turbines in developed countries have a short service life, and their manufacturers claim that the percentage of breakdowns is minimal, however, information about possible problems is presented poorly and incompletely, it is mainly supplemented during operation. Also, many workers point out that the danger in this area is at the same level as in any other industry. For example, falls from a height can occur both when working in the mining industry and when working on a wind turbine.

However, it is necessary to accept and take into account other specific conditions that may arise, for example, weather conditions or being in hard-to-reach areas. The combination of such conditions and the lack of experience and necessary qualifications of workers in the field of wind energy leads to problems with their health and safety in general. Over the past decade, according to experts, accidents at wind turbines have become more frequent, and their number is directly dependent on the number of new turbines, that is, the more turbines are built, the more accidents there are.

SWIF analyzes the number and basic information about accidents and incidents at various production facilities, including wind farms. Thus, since 1970, the number of accidents has reached 2,500 units, with most of them occurring in the last 3-5 years. On average, there are about 200 accidents per year that lead to negative consequences, and safety requirements are violated. However, not all accidents are fatal; for the same period since 1970, only 213 fatal cases were recorded. They mainly occurred during the construction or maintenance of wind turbines and turbines. Other cases occurred with workers in the transport sector, they were not directly related to the production of wind energy [4].

Also, since 2012, the company began recording data on the impact of wind turbines on human health, data on noise, vibration, etc. were analyzed. It is worth noting that not only workers suffer from such impacts, but also residents of nearby settlements. In recent years, 36 requests have been submitted and processed, in which people indicated that they have a negative impact from wind turbines. It is worth noting that every year the number of requests only increases, since in 2012 only 6 people sought help, and in 2023 already 12. Many scientists believe that these figures differ from the real ones, since wind turbines can have a more detrimental effect on both workers and residents of nearby settlements.

Based on this, a more detailed study of labor protection in the field of wind energy and an analysis of standards and requirements in various countries is needed.

Materials and methods. In order to analyze the level of injuries and safety of high-altitude work at wind power plants, it is necessary to conduct a study of the standards that are used for labor protection in this area, consider possible risks, the number of injury cases, and formulate problematic aspects and directions that can be proposed to minimize possible risks and threats. As part of the scientific work, a critical analysis of the main safety standards of various countries was carried out, statistics of victims of accidents related to labor activities, including fatalities at wind power plants, were considered.

The purpose of this scientific article is to identify the existing methods of ensuring personnel safety at wind power plants in various countries, as well as to study possible problematic aspects [5].

At the same time, special methods of collecting information were used to achieve the goal: statistical analysis, with its help the number of injuries and other safety violations in the field of wind energy was considered; topographic method, with its help the location of wind power plants in a particular country was considered; monographic

method, with its help the analysis of literature on the research topic is carried out, as well as the content of standards that are applied in this area, but in different countries.

Results and discussions. Currently, there are two main aspects that can cause problems in the field of labor protection and safety at wind farms. The first aspect is related to the fact that international regulations have not been developed properly, there are problems in standardization. The second aspect is related to the inexperience of workers and their low level of training and qualifications. Let' s consider these aspects in more detail.

So, to begin with, it is worth paying attention to the training of workers in this area. As was said earlier, the wind energy industry began to actively develop relatively recently, in this regard, there is still no base of workers who would have significant experience and skills in the industry in question. Despite the fact that the number of jobs and graduates with similar training areas is growing every year, there is still a shortage of experts. The rapid development of the industry does not correspond to the speed of personnel training, many inexperienced workers can participate in the process of casing installations, turbines, which ultimately leads to safety violations and injuries [6]. The main reason that can lead to safety violations and injuries to workers with little experience is the lack of a single standard that would regulate the practical skills of workers in the wind energy sector. Currently, there are many different standards that define the rules of conduct for workers, but there is no common one that would regulate safety rules in the wind energy sector. Small companies do not have the necessary funds to train workers and familiarize them with various standards when working on land or at sea, in this regard, they have a low level of training and qualifications, which entails possible violations. Larger companies that have funds for training and familiarizing workers with all standards can often neglect this, since time is needed for training, and money can be directed to a more attractive direction.

However, all personnel who are at the wind farm are required to know the minimum safety requirements, which can be useful in various areas of work. Let' s consider the safety requirements in more detail.

The first group of requirements relates to activities at height. In this case, the employee must know the safety precautions when working with turbines, take into account all the risks and dangers that he may encounter. He must also know the rules for handling personal protective equipment and the rules of conduct in an emergency. The employee must have rescue and evacuation devices. The second group of requirements includes the rules of conduct in the water, the employee must know how to move from a ship to a pier or to a wind turbine, how the global marine communication system is used, what personal protective equipment exists and how they are used in the water. The third group includes the rules for manual handling of goods, it includes knowledge of the methods of safe transportation of goods and special equipment for work, identifying aspects that can negatively affect health and cause injury, ways to prevent traumatic events and solve problems in the field of wind energy associated with improper movement of cargo and equipment [7]. The fourth is the standard rules for first aid, this includes knowledge and skills in providing assistance in case of injuries and illnesses, rules of conduct in emergency situations, methods of providing first aid to victims. The final group is behavior in case of fire hazard, workers must know the rules for preventing fires, be able to identify sources of ignition and quickly respond to a possible fire, assess the consequences of a fire. In general, it is worth noting that all companies operating in this industry strive to provide their employees with all the necessary knowledge, skills and abilities, with which they can not only perform assigned tasks, but also ensure a high level of safety. For this, special courses, training and retraining programs, training programs can be created, but at the same time, they are not always sufficient in full. According to scientists, in order to better improve the level of knowledge of personnel in the field of safety, it is necessary to create special courses on the basis of research institutes that would

contain programs aimed at training workers in the wind energy sector. Within the framework of such programs, courses on the operation of turbines, their maintenance and safety at stations can be organized.

With the development of the wind energy sector, more and more experts in this field appear, with their help it is possible to reduce the shortage of unskilled personnel, transfer useful experience and information. Also, it is worth considering the creation of a special unified standard that will help in training new specialists. In addition, another solution for attracting highly qualified personnel may be their transition from other related industries. Such specialists will also be in demand in wind energy, since they will have experience and all the necessary knowledge. An example can be workers from the oil or gas sector, since their working conditions are similar to the area in question. All the presented conditions will have a positive impact on the wind energy industry in one way or another [8,9].

Next, it is worth moving on to considering specific requirements and standards that can be used in the field of labor protection in the framework of wind energy in different countries.

To begin with, it is worth paying attention and considering what standards in the field of safety of high-altitude work at a wind power plant are adopted in Kazakhstan. As in other developed countries, the government of Kazakhstan is aimed at developing a ”green” economy, in this regard, a decision has also been made to develop the wind energy sector. Thus, with the help of investments of about 100 billion dollars, the development of a new type of energy in the country began in 2014. In order for the new industry to bring only a positive effect within the framework of the development program of the Republic of Kazakhstan and the joint project of the Ministry of Energy and Mineral Resources of the Republic of Kazakhstan, special sites for the construction of wind power systems (TPS) with a good wind climate, located in various regions of Kazakhstan were selected (Figure 1).

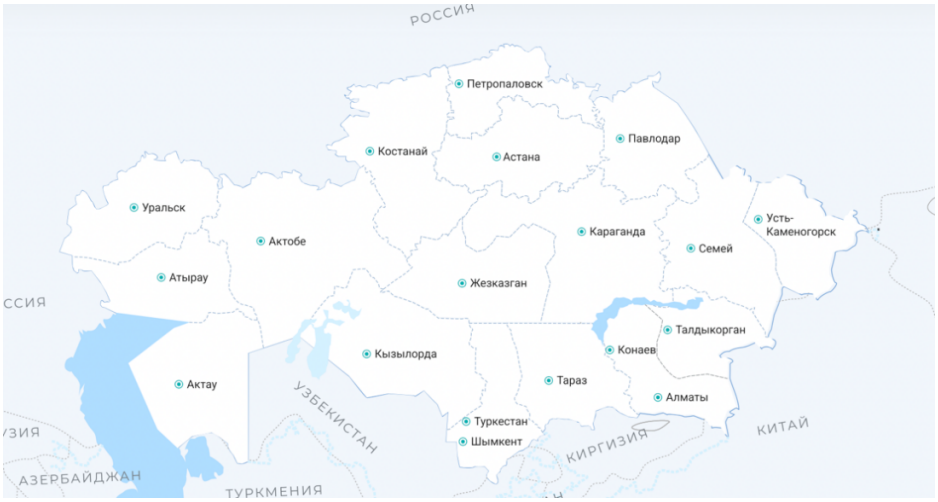


Fig.1 - Location of wind turbines in the Republic of Kazakhstan

Also, as part of the study, energy scientists developed a special atlas, which indicates areas with the strongest wind flows. An approximate assessment of the wind energy resources of Kazakhstan is included in the atlas of the main winds, it indicates that in ”50,000 sq. at a height of 80 meters on an area of more than km, the average annual wind speed is more than 7 m / s. Thus, based on the presented data, investment projects were prepared, which were then implemented and thereby new wind stations were built. So, over time, their total capacity reached $ 3 billion per year. kWh, these stations can generate about 1000 MW of electricity. ”Based on the indicators of the

program, which is aimed at the development of this area, it follows that by 2030 the capacity of these installations should reach about $ 5 billion per year. kWh. Noticeable prospects are due to the fact that the Republic of Kazakhstan is rich in winds, it is necessary to use them in the right direction and produce ”clean” energy.

According to some data, the theoretical wind generator of Kazakhstan amounted to about 1820 billion dollars kWh.hour per year. ”Considering the power density of the wind power plant at the level of 10 MW / km2 and the presence of significant free spaces, it is possible to predict the possibility of installing a wind power plant capacity of several thousand MW in Kazakhstan. The average annual wind speed in the Dzungarian Gate area at a height of 50 meters is 9.7 m / s, and the wind flow density is about 1050 W / m2. This allows you to produce 4400 kW per year. Here, a special place is occupied by the electric power purpose. The availability of free space is about 1 billion dollars allows you to install a wind power plant capacity of several MW with an annual output of kWh electricity is required. Currently, a pilot thermal power plant with a capacity of 5 MW is being built in this area. If the experience is successful, the operational capacity of the thermal power plant can be increased to 50 MW.”

As in other developed countries, wind energy does not cease to lose its momentum of development and in Kazakhstan, following foreign experience, more and more construction of new wind installations is planned, the first stations were launched in the capital of the Republic of Kazakhstan, then, having shown high results, construction continued in other areas, so stations were opened in Mangistau and Akmola regions [10]. Thus, currently in the Republic of Kazakhstan there are about 83 stations, the total capacity of which reaches 1410 MW.

In order to organize the work of these stations in the country, one of the leading and successful companies currently operates, VISTA INTERNATIONAL LLP. In 2014, it implemented the first project in the field of wind energy, so with its help, the Kordai wind power plant was put into operation. Today, this station is considered advanced, it is equipped with the most modern and innovative equipment, it also has the support of various ministries and departments, including the Ministry of Industry and New Technologies of the Republic of Kazakhstan (MIINT). To build the station, the company’ s employees considered numerous foreign experiences, to work out issues related to safety, equipment, technology, they adopted the experience of countries such as China, Holland and Germany. Studying the experience in foreign countries, calculating all the costs and logistics, a wind power plant was built in Kazakhstan. At the same time, it had a positive effect not only on the environment, but also provided an opportunity for the employment of a large number of citizens. Thus, based on this experience, other wind power plants were put into operation in the country. At the same time, the main aspect for their successful work remains occupational health and safety of high-altitude work. High-altitude work at wind farms is usually associated with the installation, maintenance and repair of equipment located at a considerable height, which requires special attention to safety issues. The main risks include falls from height, which can occur due to insufficient insurance, improper use of personal protective equipment or unexpected exposure to external factors such as strong wind or rain. For example, strong gusts of wind can lead to loss of balance and falls, which makes it necessary to take wind speed into account when planning work at height. It is also important to consider that low temperatures can cause frostbite and reduce the performance of employees, which requires them to be especially careful and use protective clothing. In addition, precipitation such as rain or snow can worsen the grip of shoes on the surface, increasing the likelihood of slips and falls [11]. Workers must be trained to recognize adverse weather conditions and take the necessary precautions, such as the use of special equipment and personal protective equipment. It is also worth noting that climate change as a result of global warming may increase the frequency of extreme weather events, which requires a revision of safety standards and adaptation of working practices at

height.

Taking climate factors into account in the process of risk assessment and planning of work at wind farms is becoming essential to ensure the safety and health of workers, as well as to effectively perform tasks in a changing environment. An important aspect is the need for regular monitoring of meteorological conditions. The use of modern technologies, such as weather stations and weather forecasting systems, allows for early assessment of risks and the adoption of measures to minimize them. For example, if strong winds are expected, work at height may be suspended until conditions improve.

Practical risk analysis and assessment in the context of high-altitude work at wind farms in Kazakhstan require an integrated approach that takes into account both the specific conditions of the region and the general trends of the transition to a green economy. An important aspect is the identification of risks associated with working at height, including both physical and organizational risks. In order to assess how safety is organized at wind farms in the Republic of Kazakhstan, it is necessary to first analyze the total number of workers at all facilities (Figure 2).

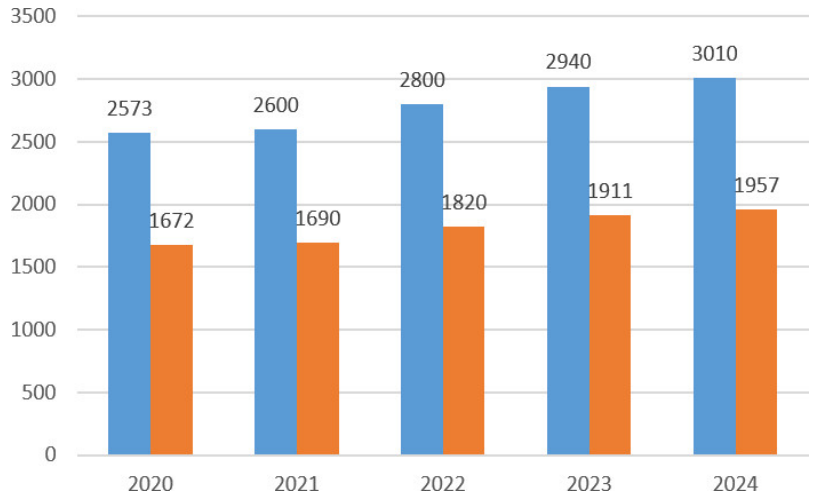


Fig.2 - Total number of personnel and those engaged in high-altitude work in the Republic of Kazakhstan, people

Thus, it can be noted that every year there is a steady increase in the number of personnel, while about 65% of the total number is engaged in high-altitude work, this is the personnel who are directly involved in servicing turbines, their repair and daily inspection. In order to ensure the safety of their activities in the field of labor protection, certain standards in the field of wind energy have been developed. Further, it is worth analyzing in more detail the content of the presented safety standards and identifying how rationally they are applied in practice. The first standard is the IEC 61400-2:2013 Standard for low-power wind turbines. Often, when characterizing wind turbines, many imagine huge turbines that are located at the height of a twenty-story building, however, over time, slightly different installations have also begun to gain popularity, they are slightly smaller in size, mainly such installations are located near residential buildings, while their power is also lower than that of large installations. Such devices are covered by the text of the IEC 61400-2:2013 standard ”Wind turbines - Part 2: Low-power wind turbines” [12].

This standard is necessary to regulate the safety rules for handling such small installations. It specifies the requirements for the quality of materials, recommendations for the efficiency of their use, installation, maintenance, and operation rules. In addition, the standard contains

safety requirements for the subsystems of these installations, including a description of how the protection mechanism is arranged, how the supporting structures, foundation, connections, and much more should be installed.

Next comes the ASTM D5741 standard, it is necessary to correctly select the surface and location of the wind turbine. In order for the installation to produce maximum power, it must be directed to the place where the strongest air flow is located. With the help of this standard, it is possible to estimate the wind at the surface and at a certain height. In addition, this standard defines the conditions under which the operation of turbines is possible, and which weather conditions are considered unsuitable for its maintenance. Also, this document can be applied in other areas of industry and in agriculture. To meet all the requirements, in accordance with the standard, the company must purchase special devices for changing. wind speed, temperature, etc., their presence guarantees the reliability of the result and the correct implementation of the theoretical aspects specified in this act.

Other standards, which are developed on the basis of consensus and can be applied to other areas, also make an important contribution to the development of wind energy. One of these is ISO 29404:2015 and ISO 29400:2015, they are necessary for the correct operation of offshore wind turbines. Such installations are considered the most complex, they are located in the open sea or ocean, and they also assume the highest efficiency [13].

Currently, in the Republic of Kazakhstan, it is planned to install similar wind turbines in the Caspian Sea, the frontal plans should assume that work in this area should be carried out only by experts in the field of wind energy, who are familiar with all the safety rules not only on the shore, but also in the water. In order to increase the level of safety in this case, knowledge of the ISO 29404:2015 Standard ”Ships and marine technology - Offshore wind energy - Data flow within the supply chain” is required. This standard defines the content and format of messages that allow monitoring the physical movement of wind turbines, as well as their components, both during the construction phase and at the start of operation. These requirements and messages can be useful not only at the beginning of work on a wind farm, but also at the time of its breakdowns and maintenance. The ISO 29404:2015 standard can be used by all companies and their employees when performing activities with wind turbines, turbines and other components. However, the standard does not apply to substations. A slightly different ISO 29400:2015 Standard ”Ships and marine technology - Offshore wind energy - Port and marine operations” is also necessary to ensure safety during work with offshore wind turbines. It defines the procedure for offshore operations, provides recommendations for the design of various installations associated with the deployment or repair of offshore helicopters. In particular, it contains requirements for the design and use of equipment, how systems and equipment are analyzed, methods and procedures for the safe execution of work on offshore wind turbines.

The next Standard is IEC 60076-16 Ed.1.0 b:2011 for power transformers for wind turbines. Transformers are the main and indispensable component of each wind farm, they are necessary so that the generated energy obtained by wind can be converted into alternating current, which is then used in the central network. Such devices are covered by the IEC 60076-16 Ed.1.0 b:2011 ”Power transformers - Part 16: Transformers for wind turbines”, despite the fact that basically all safety requirements concern high-altitude work performed with turbines, it is worth remembering that improper operation and maintenance of transformers can also lead to negative consequences for both workers and the population of the country [10].

The final standard that is used in this area is Standard AS 4959-2010 ”Measurement, prediction and evaluation of noise from wind turbines”, it also does not define safety requirements for high-altitude work, but is no less important, since it defines noise and vibration requirements, their excess can also have a negative impact on workers and residents of the country.

Thus, it can be said that in the Republic of Kazakhstan a large number of standards are used that are aimed at improving safety when working

with wind turbines at height. However, despite this, injuries and other accidents occur. According to the National Statistics Bureau of the Republic of Kazakhstan and information from the Ministry of Labor and Social Protection of the Population of the Republic of Kazakhstan, over the past 10 years, about 18 thousand people have been injured in the industrial sector while performing assigned tasks. Of these, 2,356 people were injured from falling from a height, of which about 96 people were engaged in the maintenance and repair of wind turbines. A significant number of victims is due to the fact that many workers do not have sufficient knowledge and experience when working at wind farms and high-altitude work, do not comply with safety requirements and are not familiar with the applicable standards.

Let us consider the dynamics of injuries and deaths during high-altitude work at wind farms in the Republic of Kazakhstan (Figure 3).

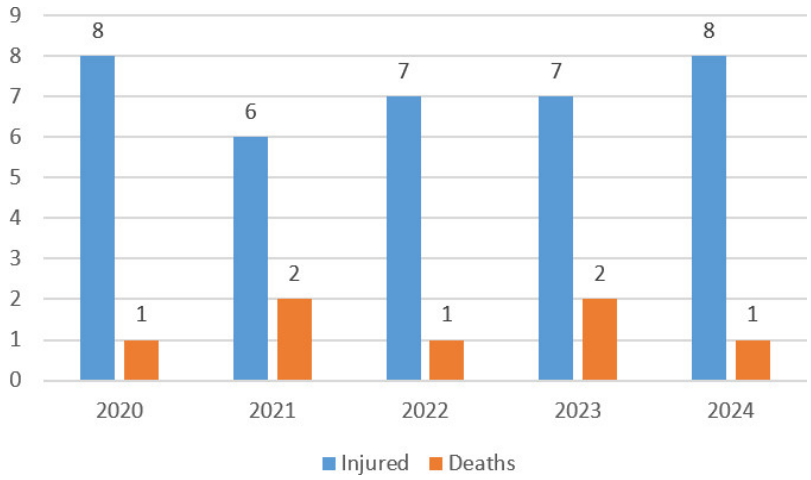


Fig.3 - Number of victims, including fatalities, during high-altitude work at wind farms in the Republic of Kazakhstan, people

That is, it can be said that about 0.4% of wind farm workers are injured and neglect safety requirements when performing high-altitude work. The most common cases of injury or death are falls from height, and falls from different heights and to different depths (in the case of wind farms located at sea) can cause harm to a person. In addition, injuries are also possible when falling on a flat surface of the same level. Falls account for more than 50% of all accidents during high-altitude work at wind farms. Similarly, falls from height and to depth can lead to fatal consequences.

Another group of factors that leads to injuries during high-altitude work is associated with damage to mechanisms; injuries occur when working with faulty turbine blades. Also, this group can include cuts and abrasions that occur when in contact with faulty tools, burns from contact with harmful substances. In addition, other types of injuries include those associated with improper actions or failure to use personal protective equipment (PPE) [14]. For example, in practice in the Republic of Kazakhstan there were cases of injury to a worker due to wear of a safety rope and slings.

In this case, it is worth saying that workers at wind farms in the Republic of Kazakhstan are aware that work is not provided for during bad weather, in this regard, injuries associated with wind and precipitation are quite rare. That is, measures in this area are being implemented in full and even those employees who have been hired quite recently are familiar with the standards in this area in detail.

The second country chosen for the analysis of safety standards was the United States. Thus, OSHA standards are currently being implemented in the country, they are rules that all organizations and

employees in them must follow in order to protect themselves from emergency situations. They are based not only on theoretical aspects, they are based on practice and can be supplemented and improved. OSHA standards are divided into several groups: general industry, construction, marine transport, agriculture. They are mandatory for implementation throughout the country, but each state can offer its own requirements for safety and labor protection at wind farms, in particular.

It is worth saying that, unlike Kazakhstan, wind energy is much better developed in the USA, there are a large number of stations that are located both at sea and on land. Also, in the USA, in general, the ”green” economy is better developed, the use of new types of energy for electricity production in the country began in the 1970s, when the government decided to combat the energy crisis with new technologies. Already in 1974, a special program was created that involved research in this area, and in 1980, the world’ s first wind farm was launched [15].

Today, in the USA there are about 9 of the largest wind farms in terms of capacity, they are located mainly in the states of California and Texas, but there are also a large number of small stations that are located in places with appropriate climatic conditions. Thus, the map of the location of wind turbines in the USA looks like this (Figure 4).

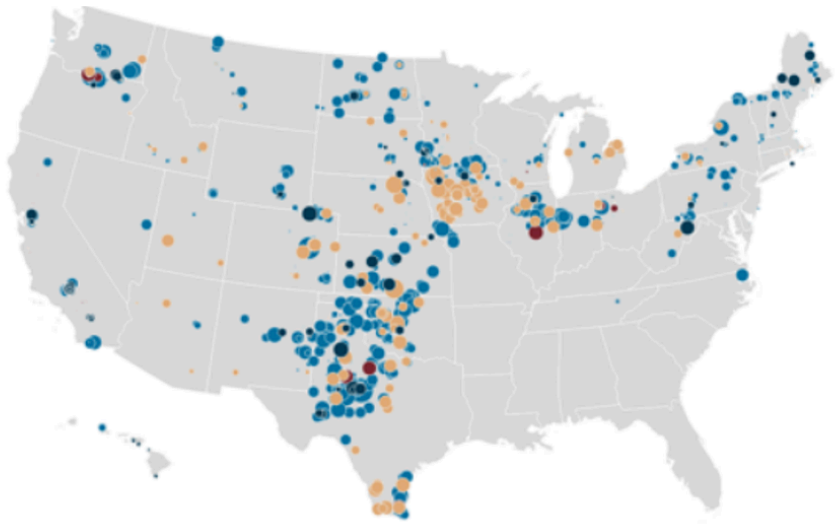


Fig.4 - Location of wind farms in the USA

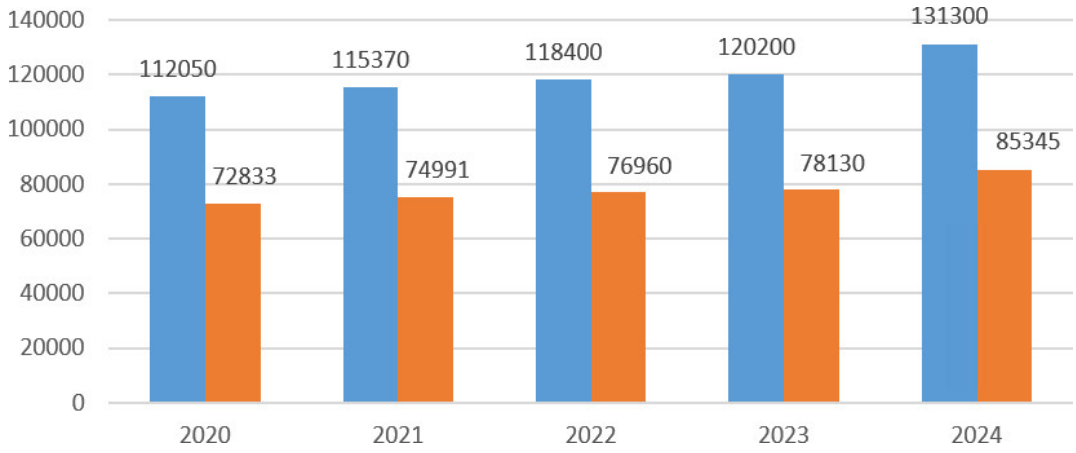


Fig.5 - Total number of personnel and those engaged in high-altitude work in the USA, people

Based on the number of wind farms, it is worth noting that they employ significantly more workers than in the Republic of Kazakhstan and other European countries. Thus, according to statistics, in 2024, more than 131 thousand people worked in this sector, which is 11 thousand more than the previous year. That is, we can say that this industry in the United States is attractive for employment, while out of the total number, about 65-70% of workers are engaged in high-altitude work (Figure 5).

The increase in the number of workers in this sector is due to the fact that new wind farms have been launched and are planned to be launched in the country between 2022 and 2026. The continued growth in the number of stations entails the need for new labor. It is worth noting that labor protection in the United States is carried out quite well, employers adhere to the requirements of the OSHA standard and communicate them to their employees, who undergo annual recertification and pass exams on knowledge of safety standards.

Thus, according to OSHA standards, the following safety requirements apply to high-altitude work at wind farms in the United States:

1. ”Maintain vertical and horizontal lift range limits. Before using the lift, operators must read and understand the manufacturer’ s instructions.

2. Control over power lines. Lift operators must be at least 10 meters away from the widest power lines.

3. Use of fall protection equipment. These include seat belts, shock-absorbing slings, and platform guards.

4. Stabilization of the lift. This is important, especially when working in windy conditions. At wind speeds over 64.4 kilometers per hour (40 miles per hour) or 48.3 kilometers per hour (30 miles per hour), if the work is related to the processing of materials, the employer is obliged to take measures to protect employees from the dangerous effects of the wind.” In addition, the GWO (Global Wind Organisation) standard is also used, it includes requirements related to working at height, actions in case of fire hazard, first aid, survival at sea, and so on. The main requirement is that when working at high-rise facilities, workers must be equipped with special protective equipment, a fencing system, a network protection system must be provided, workers must be equipped with personal protective equipment. When performing repair work or servicing turbines at wind farms, workers must generally be guided by and adhere to OSHA standards, according to which special guards must be provided when working at height, and in their absence, each worker must have personal protective equipment. With the help of handrails or netting, as well as personal protective equipment, it is possible to avoid falls or other injuries [9].

Also, workers often get injured not only when directly working with turbines, but when climbing to them on fixed ladders. ”When climbing a fixed ladder (not 20 feet long) on these towers, a ladder equipped with a cage or well shall have a landing platform every 30 feet; a ladder not so equipped shall have a landing platform every 20 feet. Ladder safety devices may be used on wind towers longer than 20 feet in place of cage protection. In these cases, a landing platform is not required.” These requirements are also set out in the OSHA standard.

However, despite the fact that there are safety requirements in the United States, similar to other countries, there are often unfavorable incidents, including injuries and fatalities. Thus, over the past 2024, there were 240 accidents and incidents in the United States that resulted in injuries to wind farm workers. Of these, 32 cases were associated with strong winds, 9 with lightning strikes, another 4 with tornadoes, cold snaps, storms and cyclones. Also, 35 cases were caused by safety violations, 9 cases with problems in electrical voltage. At the same time, the number of fatalities was 5 people (Figure 6). In this case, the percentage of injuries from the total number of workers at high-rise wind farms is about 0.3%.

Based on the increase in injuries and accidents, wind energy companies are deciding to conduct additional training and instruction for employees. Since it is the training of new employees and monitoring their activities that will help to avoid falls, injuries and other injuries in the future. Also, it is important to monitor weather conditions: in 2024,

a tornado destroyed about 10 turbines in the United States; in 2022, lightning struck several stations, which led to a fire and fatalities. Thus, we note that it is necessary to pay attention to safety in the field of labor protection in the event of various natural disasters, the evacuation of employees during a tornado or storm in particular [16].

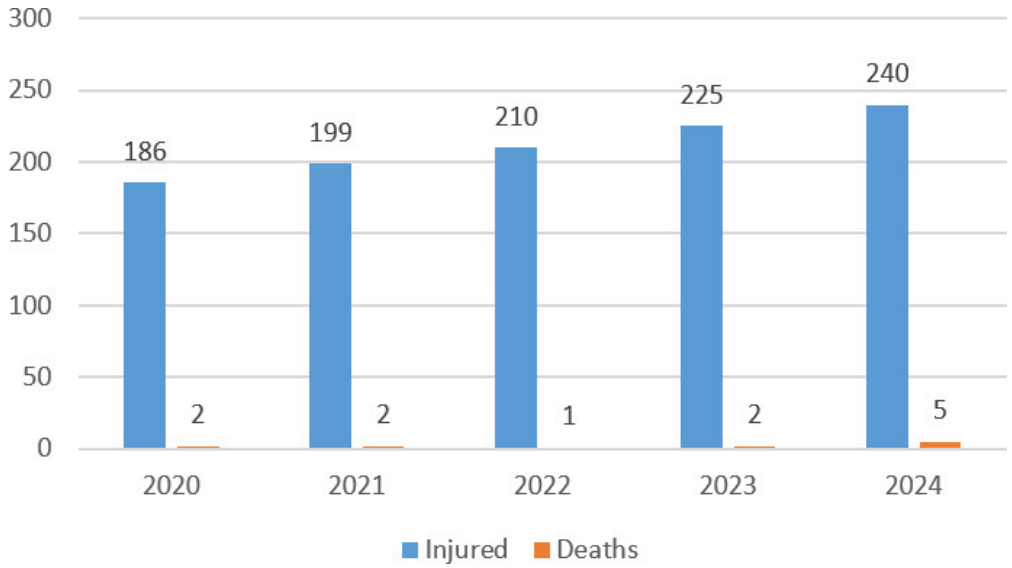


Fig.6 - Number of injured, including fatalities, during high-altitude work at wind farms in the USA, people

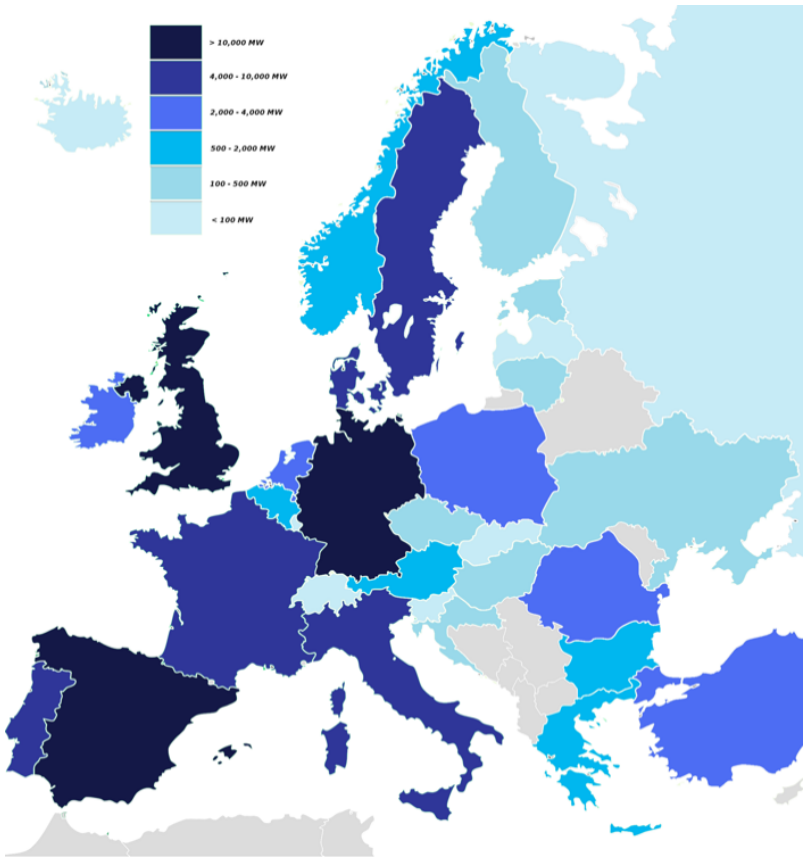


Fig.7 - Wind farm locations in Europe

Also, unlike the first example, where it was said that basically all workers do not have the proper qualifications and are quite young, the United States has an aging workforce. Many professions in the wind energy industry require not only physical strength, but also knowledge, including work at height, which includes turbine repair and other maintenance of wind turbines. This activity often has a negative impact on the health of the staff, and then on their productivity.

Thus, elderly and mature workers are no longer able to perform the assigned tasks, but at the same time, they have extensive experience, which increases their expertise in all matters. In this regard, to reduce the likelihood of accidents with elderly workers, it is necessary to develop a schedule so that they can rest and not receive additional stress. Also, it is necessary to give recommendations on changing professions, moving to administrative staff or to the company office.

The third example that will be considered in this work is the European experience. It is worth saying that the countries that prevail in the production of ”clean” energy in Europe are Germany, Great Britain and Spain (Figure 7).

To begin with, let’ s look at the safety standards that are used in all European countries when performing high-altitude work at wind farms [17].

The first standard is the European standard EN 50308:2004 ”Wind turbines. Protection measures. Requirements for design, operation and maintenance”, it is considered the most complete, since it contains all the necessary labor protection conditions in the field of wind energy, and also considers all aspects from the moment of transportation of turbines to the place of their operation. Let’ s look at the main aspects of this standard:

1. The design of wind farms should be carried out in such a way as to reduce all possible risks to the health of workers and citizens.

2. The edges of turbines that are publicly accessible should not have sharp corners, uneven surfaces and should not cause injury to workers.

3. Operational control of the turbine should be carried out without climbing to it.

4. Control panels should be located in a place that prevents accidental actions or unintentional errors of personnel.

5. During repair work or maintenance of turbines, blocking and forced shutdown must be provided.

6. All safety measures must be observed to avoid accumulation of hazardous toxic substances, flammable or explosive gases in any areas of the wind turbine [8].

It can be said that this standard, unlike those discussed earlier, contains the most complete and detailed list of safety precautions; familiarization with this standard can reduce the level of injuries and other accidents at work. However, its requirements do not apply to installations that were put into operation before 2004.

Also, when working at wind farms in Europe, quality standards ISO 9001, ISO 14001 and OHSAS 1800 are actively used. These standards include general requirements for labor protection, quality management, management, however, they do not directly relate to wind energy, but manufacturers strive to comply with them. Specifically, the IEC 61400 series applies to wind turbines; this standard covers requirements for turbine design, reliability, service life, and installation. It contains requirements for all aspects of the design, construction, and operation of an offshore wind farm. This standard is necessary so that the turbines perform their functions as reliably as possible during operation. In addition, the National Institute for Occupational Safety and Health (NIOSH) operates in Europe, which was organized back in 2009, and courses and seminars are currently held on its basis, which are also useful for health protection. An example is the seminar ”Making Green Workplaces Safe” within the framework of the ”Prevention through Design” initiative. At such meetings, specific problems in the field of labor protection are discussed and new directions for minimizing risks in production are proposed. Thus, one of the new issues is the need for uniform standard codes for the entire life cycle of wind turbines [18].

In addition to this organization, the European Wind Energy Association (EWEA) operates in Europe. Its mandate includes training new employees, familiarizing them with safety rules in the industry and in specific areas, which helps reduce risks and injuries. The organization publishes all safety requirements that are relevant for managers and employees, with special attention paid to first aid procedures. EWEA documents contain requirements that relate to safety both on water bodies and on land. EWEA proposals and organization documents can be considered international and used for labor protection in other countries. Many organizations that install and operate wind turbines are also interested in developing and using safety standards. An example is RenewableUK, which has created its own labor protection forum, which contains various training courses, a description of currently available standards and requirements. In addition, the G9 Wind Energy Health and Safety Association (G9) has been created in Europe. Its main goal is safety and labor protection in the wind energy industry. To achieve the goal, the association' s management allocates resources for conducting courses and training specialists, thereby reducing the risk of injuries and other unpleasant situations. This association, in addition to considering safety in the context of wind energy, also pays attention to offshore operations that are associated with wind turbines at sea or in the ocean and lifting operations that are associated with construction.

It is worth noting that despite a fairly wide list of requirements and standards in Europe, there is a shortage of articles on the safety of wind turbines in the marine space, and there are also no requirements for checking the durability of installations. For example, at present, a standard has not been developed that would apply to medium-sized turbines; standard requirements are used for them, similarly, there are no requirements for small wind turbines. Despite the fact that each company in this area is able to develop its own safety requirements, they need to be unified within the framework of national or international standards. Since with their help, safe work is possible.

As an example of a European country, it is worth considering the experience of Great Britain and identifying the number of injuries and other accidents when working at height. Thus, based on SafetyOn data, the following information was obtained on the total number of incidents at wind farms (Figure 8) [19].

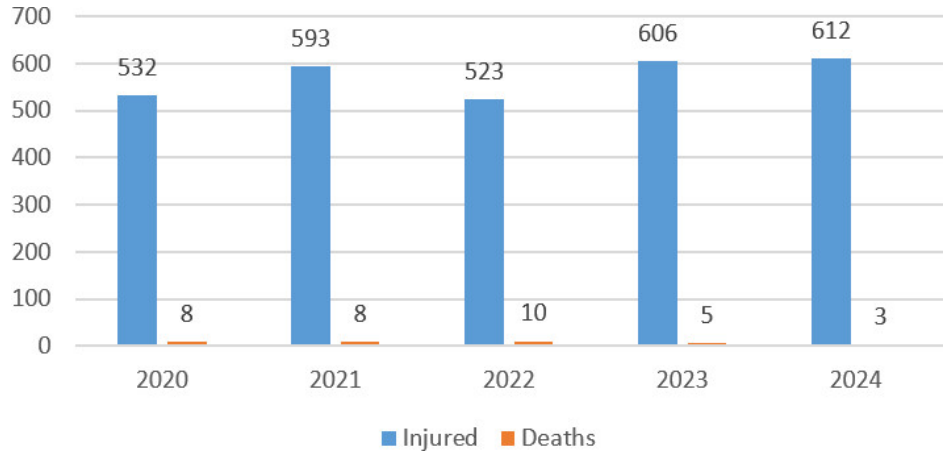


Fig.8 - Number of casualties, including fatalities, during high-altitude work at wind farms in the UK, people.

At the same time, according to statistics, the nature of accidents is not specified, whether they occurred while working at height during maintenance of wind turbines or not. However, the data show that work at stations has a high risk to the health and safety of personnel. Workers must understand that their health protection is exclusively in their hands, ignoring safety requirements cannot lead to positive consequences.

Table 1 - Comparative analysis

Country	Standards	Problem areas	Number of injuries and accidents	Conclusion on the effectiveness of the standard
Republic of Kazakhstan	IEC 61400-2:2013 IEC 60076-16 ASTM D5741 ISO 29404:2015 ISO 29400:2015 AS 4959-2010	1.Lack of requirements for different types of wind turbines. 2.No mandatory safety training for young professionals. 3.Fragmentation of standards and lack of clear coordination between them create difficulties in their application.	0.4% of all those engaged in high-altitude work	The most common cause of injury or death is a fall from a height. The second group of factors - injuries occur when working with faulty turbine blades (cuts and abrasions). Other types of injuries include those associated with improper actions or failure to use personal protective equipment (PPE). For example, in practice in the Republic of Kazakhstan there were cases of workers being injured due to wear of a safety rope and slings.
United States of America	OSHA Standard GWO (Global Wind Organization) Standard	1.Safety precautions for emergencies (storm, tsunami) are not fully developed. 2.Low level of awareness of risks among older workers.	0.3% of all those engaged in high-altitude work	Injuries are associated with strong winds, lightning strikes, tornadoes, cold snaps, storms and cyclones. Also, most cases of injuries are caused by safety violations, problems with electrical voltage.
Europe (Great Britain)	European standard EN 50308:2004 ISO 9001 ISO 14001 OHSAS 1800	1.Lack of unified requirements for fire hazard. 2.There is a shortage of articles devoted to the safety of wind turbines in the marine space. 3.There are no requirements for checking the durability of installations.	0.4% of all those engaged in high-altitude work	The most common occurrence that leads to injuries and other accidents is turbine blade failure, followed by fire.

It is worth saying that the most common phenomenon that leads to injuries and other accidents is a turbine blade breakage. Fire comes in second place, on average, about 50 fires occur annually at various stations. At the same time, turbine operators do not conduct a sufficiently accurate inspection using mechanical means, which ultimately aggravates the situation. In this case, the number of victims is about 0.4% of the total number of workers.

Thus, in order to systematize the information presented in the conclusion, it is worthwhile to make a comparative analysis of the standards considered in different countries and draw conclusions regarding their effectiveness in application, comparing them with the general level

of injuries and other accidents during high-altitude work at wind power stations (Table 1) [20].

That is, it can be said that the standards governing the performance of high-altitude work require constant updating and adaptation to modern conditions and technologies in all countries. In particular, the study highlights the current problems associated with the insufficient effectiveness of existing standards, which can lead to increased risks for workers at height [21].

Conclusions. Thus, based on the analysis of the number of injuries and accidents at heights within wind stations, we can identify some trends and main problem areas that are inherent in all the countries considered. The main problem is that technical progress in the wind energy industry is moving somewhat faster than the development of new safety standards, and therefore even experienced workers can be injured by improper operation, repair or maintenance of the turbine. It can also be argued that the hazards found in wind power plants are not too different from those that exist in other industries today (for example, falls from height, manual handling), however, it is necessary to take into account all the unique conditions that are present in the wind energy industry, and therefore the use of previously adopted safety standards and requirements for other industries is not always appropriate and effective.

In this regard, in order to reduce injuries and accidents in the work of wind turbines in the Republic of Kazakhstan, it is recommended to adopt the experience of standardizing the rules of both the United States and European countries.

It is necessary to create a specific standard that will specify all the requirements for labor protection, as well as standards for each group of wind turbines. For European countries, it is also recommended to practice actions in case of fires, since some principles of fire safety equipment of oil platforms and other energy facilities can also be applied to turbines. For the US, it is worth paying more attention to the occurrence of natural disasters and practicing storm safety rules with employees. For all countries, it is preferable to study and implement safety training for h igh-altitude work.

The basis can be the courses of the World Wind Organization (GWO). These standards include modules on working at height, fire safety, first aid, and other topics.

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