Master Thesis

Development of measures to reduce the risk of accidents and injuries in the oil mines of LLC «LUKOIL-Komi» using downhole electro-thermal complexes

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Declaration of Authorship

„I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signaled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet.”

Abstract

The graduating paper is devoted to the development of a set of measures to reduce the risk of accidents and injuries at oil mines of LLC "Lukoil-Komi" using downhole electric steam generators.

The purpose of the paper is to increase the level of occupational safety and health protection at oil mines when using the technology of modular mines and downhole electro-thermal complexes based on assessment and management of accident risks and occupational risks. To achieve this purpose their conditions of occupational safety and health of oil mines personnel and hazard identification using current and proposed technology were analyzed, a method of assessment and forecast of occupational and accident risks taking into account the production technology was developed and the obtained method under the conditions of operating enterprise was tested.

The developed recommendations on the joint use of modular mine technologies and downhole electric steam generators have shown their effectiveness in terms of industrial safety.

Zusammenfassung

Die Abschlussarbeit ist der Entwicklung einer Reihe von Maßnahmen zur Verringerung des Unfall- und Verletzungsrisikos in Ölbergwerken von LLC "Lukoil-Komi" unter Verwendung von Bohrloch-Elektrodampferzeugern gewidmet.

Das Ziel der Arbeit ist die Erhöhung des Niveaus der Arbeitssicherheit und des Gesundheitsschutzes in den Erdölbergwerken bei der Verwendung der Technologie der modularen Bergwerke und der elektrothermischen Bohrlochkomplexe auf der Grundlage der Bewertung und des Managements der Unfallrisiken und der Arbeitsrisiken. Zu diesem Zweck wurden die Bedingungen der Arbeitssicherheit und des Gesundheitsschutzes des Erdölbergwerkspersonals und die Identifizierung der Gefahren bei der Anwendung der gegenwärtigen und der vorgeschlagenen Technologie analysiert, es wurde eine Methode der Bewertung und Prognose der Arbeits- und Unfallrisiken unter Berücksichtigung der Produktionstechnologie entwickelt und die erhaltene Methode unter den Bedingungen des Betriebsunternehmens getestet.

Die erarbeiteten Empfehlungen zur gemeinsamen Nutzung von modularen Grubentechnologien und elektrischen Dampferzeugern im Bohrloch haben ihre Wirksamkeit in Bezug auf die Arbeitssicherheit gezeigt.

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Introduction

Personnel who work at the sites of oil mining are exposed to hazardous and harmful industrial factors. Specific features of the extraction technology imply heated microclimate, increased noise level and vibration, which results in increased stress on the nervous, locomotor and thermoregulatory systems of the person. In addition, exposure to several factors simultaneously increases the risk of injury or occupational disease.

According to the assessment of working conditions, the workplaces of underground oil extraction miners most often belo

ng to the hazardous class of working conditions, which is associated with a high risk of acquiring an occupational disease and getting an injury.

Since the facility is considered to be both an underground mining facility and an oil production facility, increased requirements for working conditions and production processes must be applied to it.

At present, one of the actual problems of occupational safety and health is the quantitative assessment of occupational risks, which have not been fully identified due to the lack of a comprehensive approach to the collection and management of data on the health of miners in this industry.

About thermo-mine production there are works of Vorobyov A.E. in the book "Technologies of development of deposits of high-viscosity oils of the world" or Konoplev Y.P. and Tskhaday N.D. with the work "Thermo-mine development of oil deposits" [12].

Based on the methodology of social and economic evaluation of the effectiveness of measures to improve occupational safety and health, it is assumed that companies are more correct and profitable to use preventive methods to combat employee illnesses and emergencies than to correct and (or) eliminate their consequences.

One of the ways to manage risks in order to reduce them is to change the technological process of production. At St. Petersburg Mining University, the Department of Electric Power Engineering and Electromechanics developed the downhole electrode electric heaters and electric steam generators was designed, on the basis of which an electro-thermal complex for heating the formation with heated steam was designed.

One of the ways to manage risks in order to reduce them is to change the technological process of production. At St. Petersburg Mining University, the Department of Electric Power Engineering and Electromechanics has developed an electrothermal complex for heating the reservoir with heated steam.

The purpose of the work is to increase the level of industrial safety and occupational health in oil mines when using the technology of modular mines and downhole electric steam generators on the basis of assessment and management of accident risks and occupational risks.

The main objectives of the research:

- Analyze the state of industrial safety and working conditions of employees in oil mines and identify the hazards of using conventional and proposed technology;
- Conduct a statistical study of the impact of hazardous and harmful factors of production on the personnel of oil mines;
- Develop a method for assessing and predicting occupational and accident risks, taking into account the specifics of production technology;
- Test the obtained method of risk assessment in the conditions of the operating enterprise

Scientific novelty:

- A methodology of comprehensive assessment of accidents and occupational risks for the conditions of oil mines on the basis of quantitative analysis and expert evaluation has been developed.
- The influence of industrial noise and vibration levels in the workplace on the probability of developing hearing loss and vibration pathology among the personnel of oil mines has been established.
- Practical recommendations for joint use of modular mine technologies and downhole electrothermal complexes have been developed to improve industrial safety and labor protection in underground extraction of high-viscosity oil.

1. Analysis of working conditions of oil mine workers

1.1. Prospects for production of heavy high-viscosity oil

Today, oil is an essential part of the economy of many countries and is one of the most demanded raw materials. According to the annual report of British Petroleum for 2020, a graph of oil consumption for the period from 2009 to 2019 [1], shown in Figure 1:

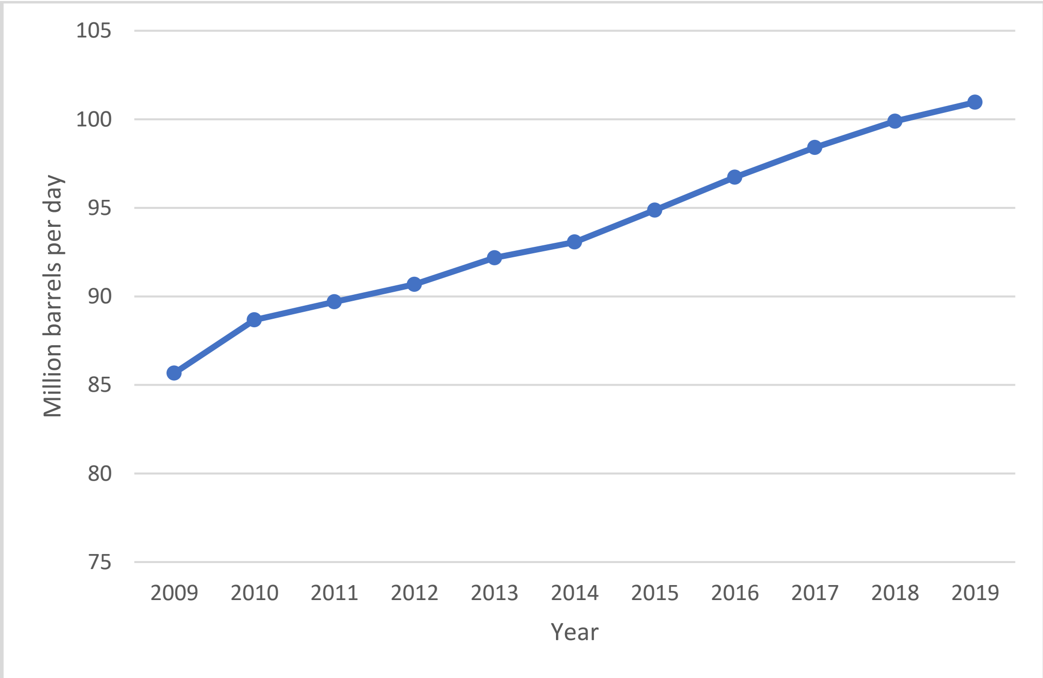

Figure 1: Rate of oil consumption from 2009 to 2019

According to statistics, a conclusion can be made about the constantly increasing consumption of oil, despite the development of alternative energy sources. With increasing consumption also grows the rate of production, which contributes to the depletion of reserves of light oil. In this regard, unconventional oil fields are becoming increasingly important.

One of the non-traditional sources of the world oil production is the extraction of heavy and extra-heavy oil. The density of this type of oil is 0.92-1 thousand kg/m3. Recoverable reserves of all types of heavy oil amount to about 150 billion tons all over the world. At present the largest volumes of extraction are achieved by Canada, which produces about 130 mln tons of such oil per year. [1] At the same time the largest resource base according to preliminary estimates is located in Venezuela - there are

47 billion tons of technically recoverable reserves of heavy oil on its territory. Heavy oil reserves in the Russian Federation are spread over many regions and amount to about 6-7 billion tons, which places the country in third place in terms of explored reserves. They are primarily concentrated in the Volga-Ural oil and gas bearing basin of the Tatarstan Republic (33% of all Russian reserves), and in the Timan-Pechora oil and gas bearing basin of the Komi Republic (23%). However, production volumes in the Russian Federation are insignificant and do not exceed 500,000 tons per year.

The main technological problem that needs to be solved in the development of these fields is to overcome its low mobility. To date, there are the following basic methods:

- In-situ – impact on hydrocarbons within the reservoir;
- Ex-situ – extraction of hydrocarbons together with the rock with its subsequent processing;
- Mining.

In Canada, the ex-situ method is predominant; half of the country's oil production comes from oil sands, which are located on the surface. One of the largest fields is Athabasca, located in the province of Alberta. The reserves of this field are estimated at 20.6 billion tons, the development of which started in 1967 and is still going on. Also in this province there are other deposits of bituminous sands - Pease River and Cold Lake.

1.2. General information about the Yaregskoye field

There is the only Yaregskoye field in the Russian Federation where oil is produced by the shaft method. The field is located 18 km southwest of Ukhta in the Komi Republic and is owned by OOO LUKOIL-Komi. The location of the Yaregskoye field in the Komi Republic is shown in fig. 2.

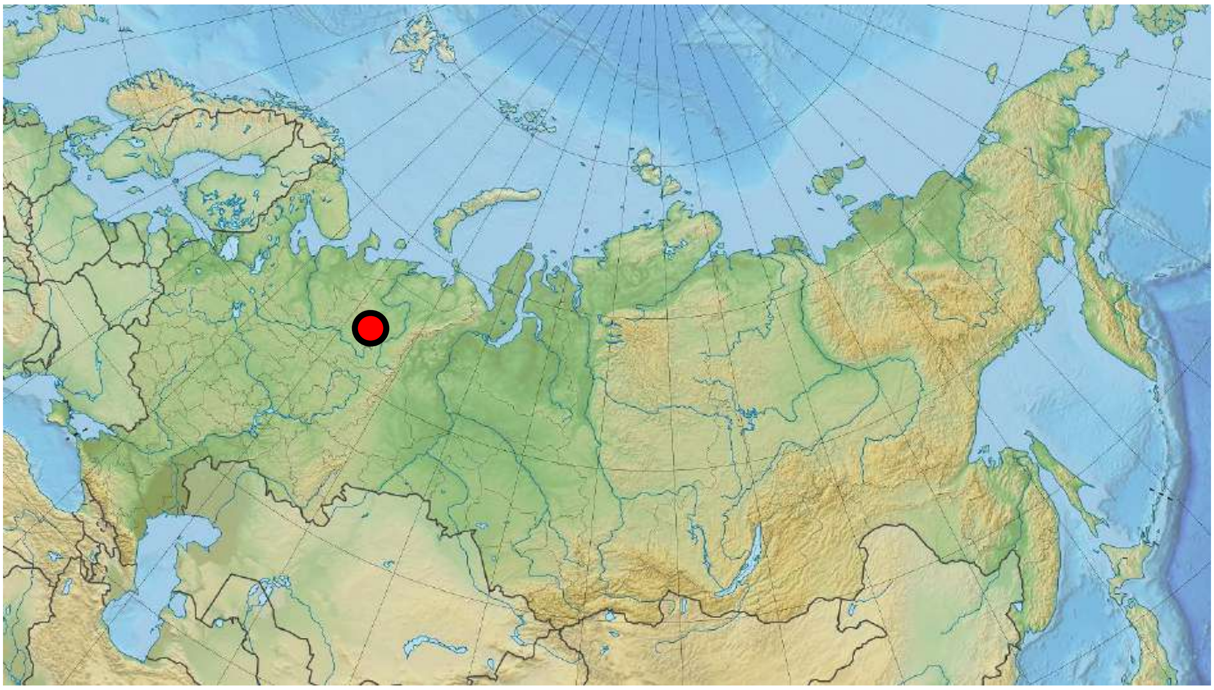

Figure 1: Geographic deposit of the Yaregskoye field

The field is conventionally divided into three oil mines, located within 3-4 km from each other, with the following names:

- Yarega (oil mine No. 1);
- Pervomaysky (oil shaft No. 2);
- Nizhny Domanik (oil shaft No. 3).

The mines are connected to each other and to the city by a year-round automobile road. The Moscow-Vorkuta railway line passes through the field between the settlements of Pervomayskiy and Yarega, with a 2-kilometer road connecting the site of Oil Shaft No. 1. [5]

The deposit is located on the border of the middle and northern taiga. The relief is forested and swampy. Absolute marks of watersheds vary from 140 to 160 m.

There is no permafrost. Soils exposed to snow surface freeze to a depth of 2.1-2.5 m.

The climate of the area is moderately cold and has a weak continental character. The climate of the area is characterized by high humidity, as well as sharp temperature and pressure drops, both daily and seasonal. According to the data of Ukhta weather station the average annual air temperature is -0,7 °C, the coldest month is -17,6 °C, and the warmest is +16 °C. The absolute maximum is +37.7 °C, and the absolute minimum is -56 °C.

The field is confined to the Yaregskaya, Lyaelskaya and Vezhavozhskaya structures, which have a single oil-saturated contour and a total length of 36 km in the central and southern part of the fold.

The lower part of the reservoir in the larger area of the field contains groundwater. The water-oil contact in the reservoir has a transition zone 2-5 m thick. Effective average reservoir porosity is 26%, permeability is on average 2.0 μm2. The formation is broken by numerous tectonic faults and a dense network of small cracks, the openness of the faults varies from fractions of mm to several cm.

The oil in the reservoir is heavy, with a density of 945 kg/m3, it has a viscosity of 5-20 Pa under reservoir conditions. Reservoir temperature is 6-8°, initial reservoir pressure is 1.0-1.3 MPa. casing head gas has a density of 594 kg/m3 and contains 95-98% methane.

The field was discovered in 1932 and test production began in 1935 using the traditional downhole mining method. However, in 1972, the field was converted to thermo-mine production. The field was unique because it was the first in the world to use this technology on a commercial scale.

In 2017. The field produced 1 million tons of oil. In 2018 a steam generation boiler complex was commissioned to increase production by 20%.

Current estimated oil reserves are shown in Table 1:

Initial reserves, A+B_1		**Oil production since the start of development**	**Residual reserves, A+B_1**		**Oil production for 2019**
oil in place	**extractable reserves**		**oil in place**	**extractable reserves**	
241419	117623	33068	210351	86555	1352

Table 1: Volume of field reserves and produced oil

With further development of the field, LUKOIL expects to increase the volume of production at the field to 7.17 million tons/year of oil-containing fluid by 2023 and more than 1.1 million tons/year of oil by 2024. Since LLC Lukoil-Komi in the future is considering continuing the development of the field we can conclude that underground oil production will be relevant to the company for decades to come.

Despite the high cost of heavy oil due to the cost of production and processing of high-viscosity oil, the necessity of developing methods to improve the technological process and increase the profitability of fields around the world will only grow because of the depletion of traditional hydrocarbon reserves. Increased interest to the fields of this type is also presented by the government of the Russian Federation in the form of formation of tax privileges for the companies engaged in extraction and processing of high-viscosity hydrocarbons.

1.3. Characteristics of the applied development systems

The field is developed in 2 main areas - Yaregskaya, where oil is produced by thermal shaft method, and Lyaelskaya, where production is carried out using technology Steam Assisted Gravity Drainage (SAGD).

The principle of thermo-mine development is a combination of the usual drainage mine development and the use of a heat transfer fluid to influence the formation. The combination of these technologies can increase the oil recovery factor when drilling wells with a depth of about 300 meters drilled from underground mine workings. Wells in the field are used as follows: horizontal, declined and up hole. The wells form a dense grid arrangement. This allows all fractures, caverns and other formations to be connected to each other to increase formation permeability. Because of the increased filtration surface of the wells, resistance is reduced and thermal exposure to the reservoir is increased. The use of dense mesh accelerates and increases the efficiency of formation warming. [5]

- Thermal mining is performed at the Yaregskoye field in several ways:
- Dual-horizon system;
- Single-horizon with delineating gallery;
- Subsurface.

The methods differ in the way steam is injected into the formation to heat it up. The dual-horizontal system consists of vertical and inclined injection wells that are drilled from the field gallery. Steam is injected into the reservoir through these wells. This development forms a supraformational network from the production gallery in the lower part of the productive formation. Oil is produced from wells that are drilled from the production gallery. The production gallery is also located at the bottom of the reservoir. This system allows uniform coverage of the development reservoir and makes it possible to optimize steam injection rates at low pressure on injection wells (not more than 0.3 MPa). The disadvantages of this system are relatively high capital costs for drilling and preparatory mining operations. Also, this system has a low coverage in the lower part of the section by the heating due to the spreading of steam up the path of least resistance and allows the formation of sand plugs on the faces. [5]

The single-horizon system with delineating drifts represents the following technology: Steam is injected through wells that are drilled from the drilling gallery. This technology makes it possible to provide the required steam injection rates at low steam injection pressures (0.2-0.3 MPa). Principle schemes of described methods are shown on figure 3.

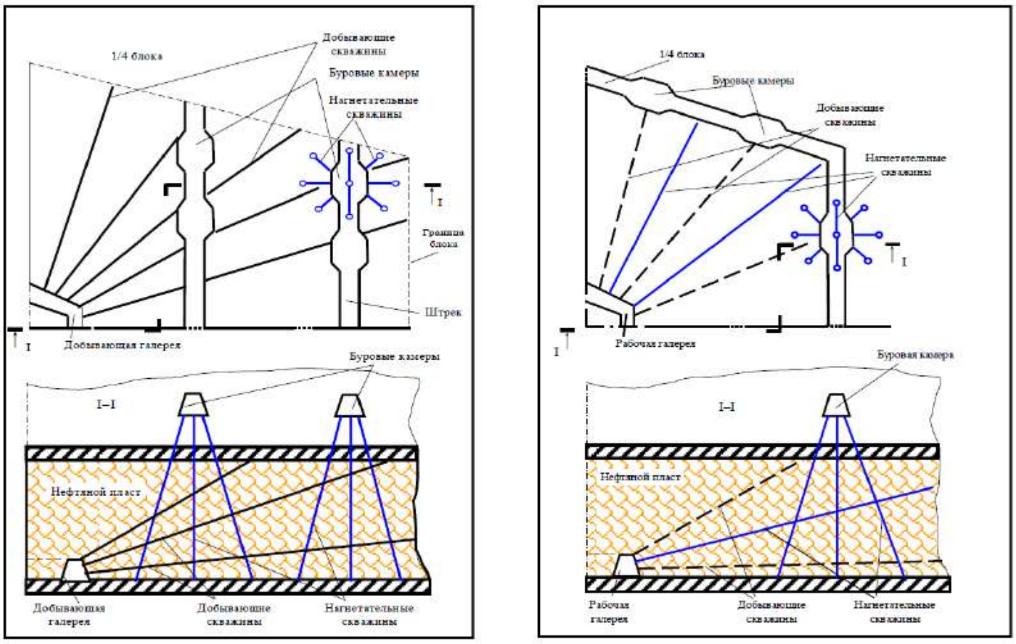

Figure 2. Schematics of thermal mine development systems

Subsurface production involves the delivery of steam through vertical injection wells drilled from the surface. Steam is then distributed through the reservoir by steam distribution wells that are drilled from underground workings to the bottoms of the injection wells. Oil is produced by means of underground production wells. The main disadvantage of this method is the necessity to drill a large number of wells from the surface, which is not always possible due to various objects located near the development system, such as industrial buildings, ponds, dumps. We should also note the low steam-oil ratio in this development system. At the same time, the method has a significantly higher oil recovery factor, which can reach 0.54 after 10 years of development. For comparison, it would take almost twice as long, from 17 to 20 years, to achieve the same oil recovery factor level with the dual-horizon development system. The oil recovery factor of single-horizon is even less. [19]

The disadvantages of mine development of oil fields are: high capital costs, the need to use devices and mechanisms in spark-proof design, stringent requirements for the state of the mine atmosphere and the use of chemical reagents for oil extraction. [20]

1.4 Analysis of hazardous and harmful industrial factors in the workplaces of oil mines.

The government, employers, and businesses are interested in making workplaces safer. To this end, legislation is being improved and measures are being taken to modernize production. The primary tasks in the field of labor protection today are to minimize the impact of hazardous and harmful factors of the production environment on workers, and to create safe and comfortable working conditions at the workplace. Safety and health in the workplace have become a key focus of production development programs around the world.

The employer maintains continuous production control, the objectives of which are:

- Control of compliance with industrial safety and labor protection requirements;
- Development of measures to improve working conditions;
- Survey of the current status of industrial safety;
- Formation of works directed to the prevention of accidents at hazardous facilities, as well as the development of methods for their localization and elimination of consequences in case of an accident;
- Control over the timely performance of the necessary tests and technical inspections.

Mine development of oil fields, although perspective, but still is an understudied technology with a short experience of production operation. [6]

Actual data on the distribution of hazardous and harmful production factors, which may cause the acquisition of occupational disease in the oil industry of the Komi Republic, are shown in Fig. 4.

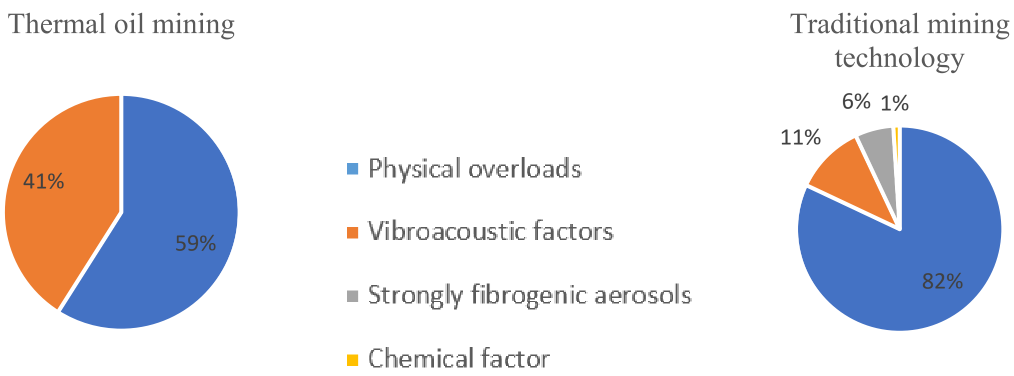

Figure 4: Distribution of harmful factors causing occupational diseases of oil industry workers in the Komi Republic

As the technology of oil extraction by the mine method is unique, it also forms its own structure of harmful and hazardous industrial factors. This structure cannot be compared with underground coal mining or surface oil extraction. Experience of these mining methods should be taken into account, forming their own unique structure of hazardous and harmful industrial factors, and form methods of risk assessment at such enterprises.

Working conditions for underground personnel of oil mines are represented by a complex of production factors:

- Increased dust content in mine air;
- Low illumination of workplaces;
- Heating microclimate;
- Increased content of acyclic hydrocarbons in the air;
- Increased values of vibroacoustic factors (noise, local and general vibration).

Specific working conditions in oil mines (danger of cave-ins, darkness, presence of mine gas in the atmosphere) form significant difficulties in control and management of the production process. Heated microclimate conditions create additional difficulties for the personnel. However, this extraction method is widely used at underground fields due to its high extraction rate and oil recovery factor.

According to data from Yareganeft company, which includes 3 oil production mines, the total number of workplaces is 436. At that, the number of workplaces with no hazardous factors detected is 77, and the number of workplaces with working conditions worse than permissible ones is 359. Table 2 shows the distribution of harmful and dangerous production factors at workplaces:

Name of the harmful and hazardous production factor	Number of workplaces, pcs.
Chemical	96
Strongly fibrogenic aerosols	77
Noize	341
Local vibration	59
Microclimate	78
Heavy manual operations	179

Table 2: Distribution of harmful and dangerous production factors in the workplace

From the table above it is possible to make a conclusion about the most frequent harmful and dangerous factors - 40.88% for noise and 21.46% for heavy manual operation. Levels of labor process severity are most common among workers associated with lifting and moving excessive weights by manual labor, and mid-level professionals due to the use of a large number of control and measuring devices throughout the work shift. This hazard can affect the locomotor system and cause diseases.

Increased noise level is observed in the workplaces associated with tunneling works. The main sources of this factor are jackhammers, rotary hammers, harvesters, fans and other machines and mechanisms. To reduce the noise level, fans are equipped with noise absorbers, and employees use personal protective equipment.

Another harmful factor that can affect the human body is the dustiness of mine air. Dissertation work by Nor E.V. [15] reflects the process of research of dustiness level both during drilling with water irrigation and without dust suppression. The results of this study showed that the concentration of dust during drilling exceeds the maximum permissible (2-4 mg/m3) by hundreds of times.

The consequence of a heated microclimate is a strain on human thermoregulation. The increased temperature of the environment affects the physical activity of the person throughout the workplace. [2] The critical level of influence of this factor can cause heat stroke, which contributes to the development of occupational diseases, and can also cause an accident. The accident statistics at the Yaregskoye field recorded a fatal accident due to overheating of workers in January 2015. A total of 4 accidents caused by extreme temperatures were recorded in the field between

2003 and 2020. In addition, the heated microclimate in combination with increased humidity has a negative impact on the body's resistance to other harmful production factors. [21]

Acquired and developing occupational diseases are a consequence of increased risks of accidents and injuries in the chain of technological process due to increased influence of human factor on the production process (not timely evacuation, omission of evacuation signals, incorrect work with working tools, etc.).

Injury trends for the period 2003-2020 are shown in Figure 5:

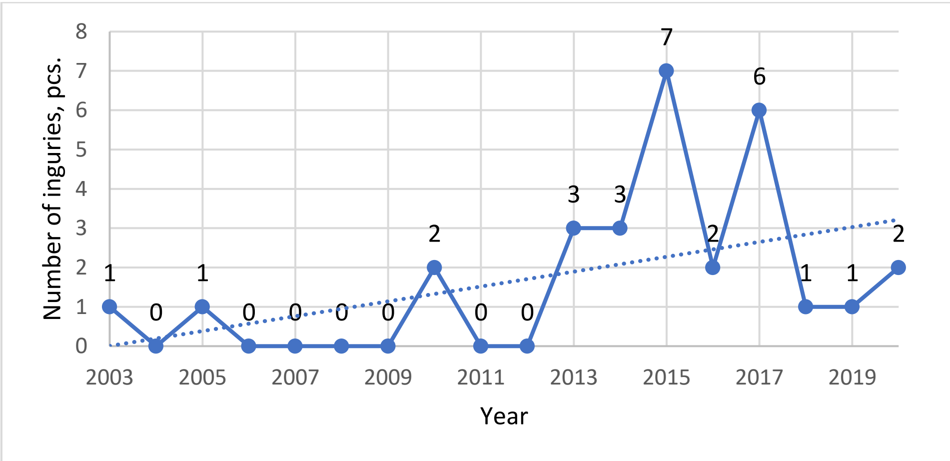

Figure 5: Incident trends 2003-2020

According to this graph, the number of accidents has been increasing over the years. One of the reasons for this trend is the increasing intensity of oil development and production over the years.

Fig. 6 shows the proportionate distribution of injuries according to the severity of the consequences.

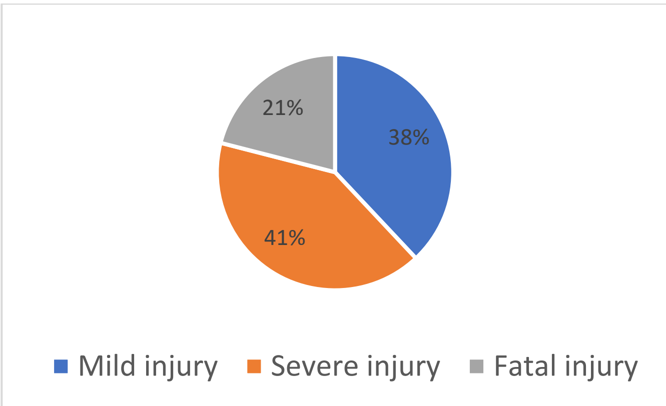

Figure 6: Percentage distribution of injuries for the period 2003-2020 according to the severity of the consequences

This chart shows that most injuries end up with severe consequences, indicating increased risks in the workplace.

The main causes recorded during accident investigations are:

- Violation of occupational safety requirements;
- Unsatisfactory organization of production work;
- Rock failure

Major process deficiencies that are a potential cause of illness and/or injury:

- mining equipment, the operation of which requires contact of employees with vibration generating equipment;
- No reduction in the period of work with various vibration generating equipment with an increase in work experience;
- Absence of deep process automation, which reduces or eliminates the physical workload on the employees;
- Absence of a comprehensive approach and continuous monitoring of employee health. The consequence of this is the impossibility of qualitative assessment of the health risk of employees during medical examinations (preliminary and periodic); [3]
- Workers ignoring their own level of health, as well as widespread bad habits (alcohol abuse, smoking, etc.).

Conclusions of chapter 1

1. Due to the gradual depletion of reserves of traditional hydrocarbon fields, the relevance of development of heavy and high-viscosity oil fields increases. Physical properties of this type of oil differ from traditional, which leads to specific technologies of development and oil production in these fields and determines the peculiarities of working conditions
2. Analysis of statistical data on injuries and occupational diseases showed that, despite the existing regulatory and legal framework of requirements for working conditions and labor protection, the issue of safety in the workplace of miners still needs to be improved.
3. The results of the analysis of harmful and dangerous production factors made it possible to identify the main sources of occupational diseases and injuries. These harmful and dangerous production factors are: vibration, noise, heated microclimate, hard work, as well as failure to comply with labor protection requirements at the workplace by employees – the human factor.

2. The current state of problem research

2.1. Actuality of the problem

Personnel working in oil mines are exposed to dangerous and harmful production factors. Specific features of the extraction technology imply a heated microclimate, increased noise and vibration level, which results in increased stress on the nervous, musculoskeletal and thermoregulatory systems of the person. In addition, exposure to several factors simultaneously increases the risk of occupational disease or injury.

В настоящее время одной и актуальных задач охраны труда является количественная оценка профессиональных рисков, выявление которых не произведено в полной мере из-за отсутствия комплексного подхода к сбору данных о состоянии здоровья горнорабочих данной отрасли, и их управление.

At present, one of the actual tasks of labor protection is the quantitative assessment of occupational risks, which have not been fully identified due to the lack of a comprehensive approach to the collection of data on the health of miners in this industry and management of identified risks.

One of the ways to manage risks in order to reduce them is to change the technological process of production. The Department of Electric Power Engineering and Electromechanics of St. Petersburg Mining University has developed and designed a design of an electric steam generator for thermal impact on productive formations.

Another argument proving the relevance of this problem is the fact that the current field located in the Yaregskaya area (Fig. 7) will soon be depleted. The northern section and the Lyaelskaya area have additional proven high-viscosity oil reserves, but application of the existing technology requires higher costs for steam generation, mining operations and construction of steam pipelines over long distances. These cost components make the development of these fields unprofitable by the traditional method. For this reason, LLC Lukoil-Komi is performing a patent analysis in order to find a different method for increasing the oil recovery factor and profitability of the project.

Figure 7: map of the Yaregskoye field

2.2. Existing risk assessment methods

All activities of organizations have certain risks. Risk management allows making the right decision in conditions of uncertainty and the possibility of an event negatively affecting the company's work.

Risk assessment can be based on the results of qualitative, quantitative and semi-quantitative analysis (Fig. 8).

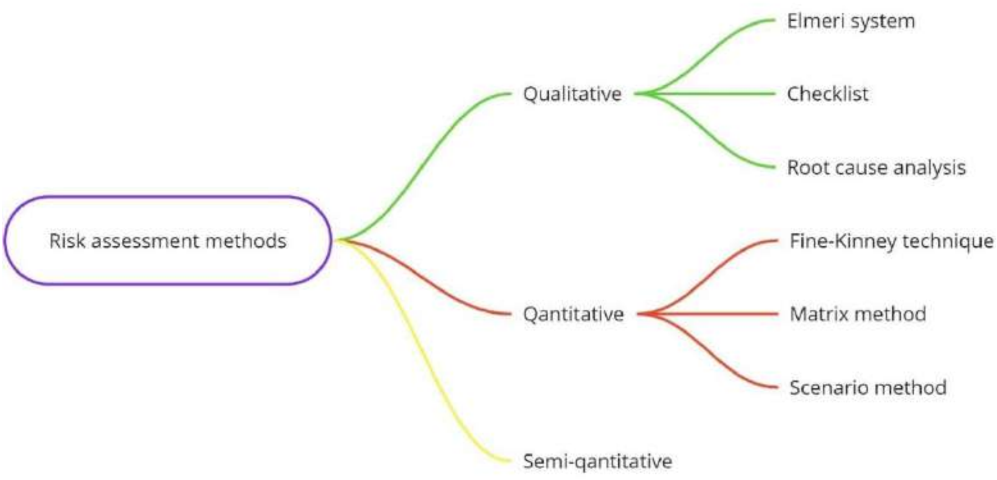

Figure 8: Classification of assessment methods

The principle of quantitative risk analysis - a numerical measurement of the impact of changes in the factors of the project tested for risk, on the behavior of the performance criteria of the project. Quantitative risk assessment allows you to determine:

- The probability of the event occurring;
- The degree of impact of the risk and the amount of unanticipated costs of remediation;
- Risks that require early response and more attention, as well as the impact of their consequences on the project.

The disadvantage of this method is the need for an extensive and reliable statistical basis for the analysis, which makes it impossible to assess some factors or makes it difficult to assess them in the absence of monitoring of this factor. Quantitative methods include the Fine-Kinney technique, the matrix method, and the scenario method. [17]

The Fine-Kinney technique is based on the multiplication of three components: the degree to which a worker is exposed to a hazard in the workplace, the probability of a hazard in the workplace, and the severity of the consequences for workers if the hazard were to materialize. The method is simple to calculate mathematically and illustrative, but involves subjectivity in the evaluation.

The matrix method is based on the calculation of the probability of dangerous situations and the level of severity of consequences for the safety and health of the employee. It is illustrative, as it allows ranking risks, but requires preparation of the structure of scale criteria in the matrix and has low objectivity.

Qualitative risk assessment allows to reveal and identify possible types of risks in the process of qualitative analysis of project risks, which includes the descriptive aspect of determining those or other types of risk of the project. The advantages of this method are that it can be used in the early stages of projects without a quantitative data base to assess them and make initial conclusions about the degree of safety in production. The disadvantage of this method is the subjectivity of the data obtained. Qualitative risk assessment methods include the Elmery system, the Checklist, and root cause analysis.

Elmery's system is based on observations that cover all the component parts of workplace safety, such as:

- Usage of protective equipment;
- Workplace cleanliness;
- Occupational health and safety when working with machinery.

This method allows direct planning of measures to eliminate the identified non-compliance. The disadvantages of the method are the inability to rank the risks in order to eliminate the most dangerous ones first, and the requirement for continuous monitoring and analysis.

The checklist allows to conduct an express analysis in order to form a list of risks without assessing the level of influence of these factors on the level of professional risks of employees. Advantages of the method are flexibility in application and speed of analysis, disadvantage – complete absence of risk ranking.

Root cause analysis is a method that identifies the root cause of the hazard. A detailed analysis makes it possible to determine at what stage of production and there is a need to improve safety and in what ways this can be achieved. The disadvantage of this method is the need for a hazard to cause harm.

Semi-quantitative risk assessment combines qualitative and quantitative assessment. Such methods use numerical scales of consequence and opportunity, and they can be combined to form a level of risk using a formula. The scales can be linear or logarithmic, or have some other relationship. The formula used can also vary. The main advantage of this method of analysis is the combination of qualitative and quantitative analysis, which makes it possible to neutralize the disadvantages of each method separately, as well as to assess the level of occupational risk in its entirety.

The activities currently being carried out to control the level of industrial safety and occupational safety in the enterprises of thermal oil extraction are formed using state and corporate risk assessment, but without taking into account the deviations in the health of personnel and occupational risks.

In the dissertation work Nor E.V. " Forecast assessment of dust and gas mode of air in working zones of oil mines at steam-heat influence on a layer (on an example of the Yaregsky field of high-viscosity oil)" describes the study of dustiness level at two modes of drilling and at excavation of rocks. The result of the analysis was the conclusion that drilling creates a dust concentration many times higher than the maximum allowable (2-4 mg/m3). An increased level of dust in the working environment increases the risk of dangerous events such as a fire or explosion, and is also a harmful factor affecting the health of personnel.

There are several methods of risk assessment in oil mines at the moment. In the article of the authors T.V. Grunskaya and A.G. Berdnik "Hygienic assessment of risk of occupational diseases in workers engaged in thermal oil-mine extraction" a combined algorithm of risk assessment of getting and developing occupational diseases is proposed, the main stages of which are as follows:

- Monitoring of risk by levels of exposure to harmful factors;
- Processing of received data;
- Calculation of the risk of an occupational disease;
- Occupational risk assessments;
- Ranking the value of occupational risk and recommendations for management.

This methodology considers each type of risk separately and takes into account existing data on occupational diseases received and allows for constant updating due to the processing of new statistical data on diseases in the workplace. The disadvantages are that this methodology concerns only the risk of getting an occupational disease, without taking into account the dynamics of injuries, which does not allow to fully assess the risk in the workplace. This drawback is eliminated in the proposed methodology.

Another method is a scoring assessment of occupational risk, which is presented in the work of A. I. Fomin "Scoring assessment of occupational risk of workers of oil mines of the Yaregskoye field", which offers a summary table with a scoring system for various risk parameters. Score system implies - the higher the score, the greater the discrepancy of the state of working conditions at a particular workplace by a given harmful factor. This methodology allows to build a mathematical model that takes into account the level of exposure to a harmful factor, the duration of its exposure and the resulting attribute (e.g. the state of health of an employee). After mathematical measurement of each production factor, a generalized morbidity risk level is formed for each workplace. [4]

The disadvantage of this work is that the results of the evaluation of the degree of influence of factors were used as a point estimate. The proposed updated methodology uses statistical data and measured indicators of the impact of hazardous and harmful production factors in the workplace.

In the international experience there is no solution to this problem due to the fact that the technology of shaft oil production is unique and is used only in the Russian industry.

This work proposes to introduce a comprehensive assessment of the occupational risk of injuries, accidents and diseases of miners. The essence of the method is a quantitative analysis of statistical data on injuries and occupational diseases at the Yaregskoye field with the subsequent application of a comprehensive express analysis of working conditions at workplaces based on a point analysis.

Conclusions of chapter 2

1. The above arguments prove the relevance of the topic of work
2. In according to the advanced foreign and domestic experience the risk-oriented approach allows to solve the tasks of minimizing professional risks, accident risks and to predict the occurrence of dangerous situations, taking into account various scenarios in order to prevent them proactively. Realization of the risk-oriented approach occurs due to the use of various methods of risk assessment, taking into account a set of factors.
3. The priority method of risk assessment in the mineral resource complex is semi-quantitative, which allows to quantify the risk factors for which there are statistical studies, but also to take into account those risk factors that do not have a numerical database by the qualitative method.
4. Existing analyses of working conditions in oil mines have shown a spectrum of problems leading to high levels of risk.
5. The existing methods for assessing occupational risks in thermal mining do not allow a full assessment of the complex level of risk of injuries and accidents.

3. Development of promising technological solutions for extraction of high-viscosity oil by shaft method

3.1. Basic technical solutions for modular mines

One promising development from a social and economic point of view is modular mines.

The design of underground mines is changing the traditional approaches to more modern technologies for the opening, preparation and mining of mineral reserves on the basis of a qualitative change in the mining structure.

The mining-technological structure of the opening and preparation of the mine field, which determines the type of mine, the volume, construction time and efficiency of the mining enterprise is the most conservative part of the project of development of the mine field. The costs of clearing operations, devastation of easily extractable deposits and improvement of mechanized complexes have required changes in the methodological basis of designing strata opening and preparation methods during the development of new deposits. Modular mines simplify and unify the processes of opening of strata and production of minerals. This approach has been used for many years in the development of coal deposits, but has not previously been adapted to underground mine production of oil.

There are several options for opening the Yaregskoye field with the use of modular mines:

Option 1 – opening of modular shafts with two shafts (lifting and ventilation).

Option 2 – opening of modular mines with one lifting shaft (a ventilation well is passed for the issuance of the outgoing air jet, for the second emergency exit an emergency borehole).

Option 3 – opening with inclined shafts.

Option 4 – opening of three modular shafts by one hoisting shaft. In this variant for the outgoing air jet and the second emergency exit a ventilation well is passed on each modular shaft.

Having considered all possible methods of deposit development with the use of modular mines it is necessary to make their analysis in order to identify the most preferable. One of the key factors in the choice is the amount of necessary underground work. Full volume of mining works of each option is presented in table 3:

Type of work	Option 1	Option 2	Option 3	Option 4
	Volume, m^3	Volume, m^3	Volume, m^3	Volume, m^3
Primary period				
Hoisting shaft	13956	13956	-	4622
Ventilation shaft	13146	-	-	-
Runaway	-	-	64470	
Inclined shaft	-	-	58899	6618
Total:	27102	13956	123369	11240
Secondary period				
Drilling gallery	31332	31332	31332	31332
Service roadway	36666	42354	38283	94208
Total:	67998	73686	69615	125540
Total per both period:	95100	87642	192984	136780

Table 2: Comparative analysis of the volume of mining operations for different options

On the basis of the technical and economic calculation of LLC "Lukoy-Komi" data on the approximate number of personnel for each of the options for modular development were obtained. The results are presented in Table 4:

Personnel category	Option 1	Option 2	Option 3	Option 4
Surface workers	54	38	23	28
Underground personnel workers	43	43	37	43
Total workers:	97	81	60	71

Table 3: Number of personnel for each method of production

Based on the number the most preferable options 3 and 4, but the second option does not significantly exceed the number of personnel and is accepted better than the first system of development with the opening of 2 vertical shafts, and is much better than the current system of development.

Duration of commissioning and timing of production start are also priority factors when choosing a reservoir development technology. The timing of production in different variants of the opening, are as follows:

- Option 1 (modular mines with the opening of 2-mm vertical seams) - 3 years and 9 months
- Option 2 (modular mines with opening of 1 vertical shaft and 2 wells) - 3 years and 5 months
- Option 3 (modular mines with 16° inclined shafts) - 2 years and 8 months

– Option 4 (central hole opening with three ventilation wells) - 4 years and 10 months

Options 2 and 3 are preferable in terms of the timing of the start of production.

According to the analysis of the constituent parameters of the excavation, Table 5 presents the final conclusions on the preferred development option:

Parameter	Option 1	Option 2	Option 3	Option 4
Start date of extraction, years	3 years 9 months	3 years 5 months	2 years 8 months	4 years 10 months
Volume of mine workings, m^3	95 100	87 642	192 984	136 780
Personnel, pers	97	81	60	71
Pros and cons				
Conclusion:		The most preferred		

Table 4: The main advantages and disadvantages of the output options

Based on the above, it is concluded that the second method of development, that is, modular mines with the opening of the 1st vertical and 2-hole is considered the most preferable.

The development principle of the most preferred variant is described below. The development system offers opening of reserves by a lifting wellbore and two wells. A ventilation well is passed for issuing the outgoing air jet, for the second emergency exit an emergency borehole is passed. The principal scheme is shown in Fig. 9:

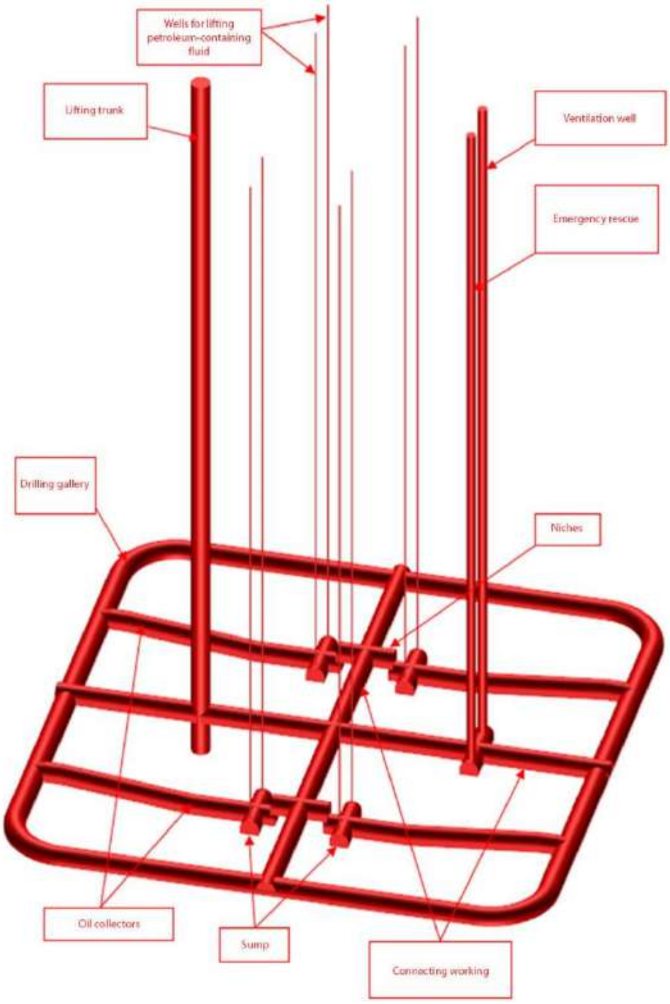

Figure 9: Isometric view of the mine according to option 2

The lifting shaft is equipped with a cage lift and a ladder compartment. Below the level of the borehole yard, there is a sump designed to collect water flowing down from the workings, as well as to accommodate lifting vessels during loading and unloading operations.

The shaft is designed for supplying fresh air, lowering and lifting people, materials and equipment. During the construction of the shaft and shaft excavations, a tunneling bucket is installed in the shaft for lifting rocks, lowering and lifting people, materials and equipment.

Ventilation well is an air-extraction well. The rescue well is equipped with a rescue ladder and is an emergency exit.

Rock mass shipment will be performed by a loading and unloading machine in the barrel of the shaft.

The mine plan is shown in Fig. 10:

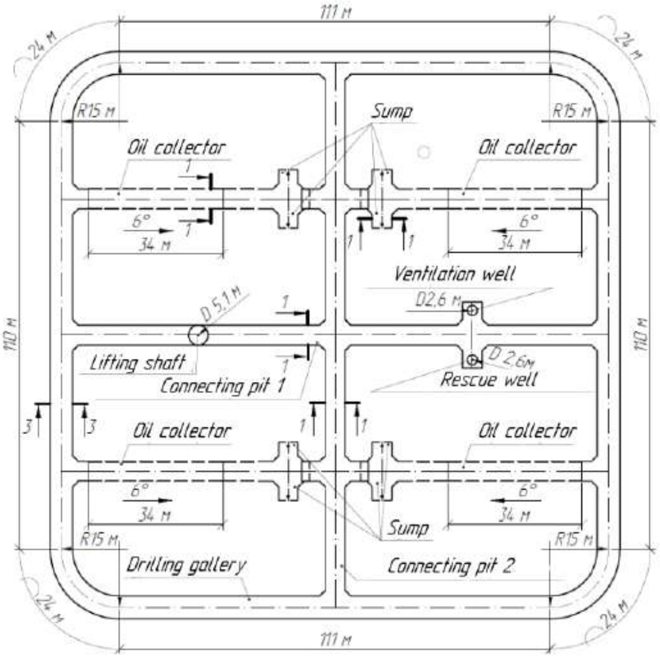

Figure 10: Plan of mine according to option 2

The second option implies the use of proven mining technology, minimal risk of steam breakthroughs into the mine workings by minimizing mining operations on the tuff horizon, and also allows for phased introduction of the borehole gallery sectors. But there is no experience of using wells as an emergency exit to the surface in this technology, which entails economic and professional risks.

3.2. Application of downhole electric steam generators for enhanced oil recovery

Electro-thermal downhole devices developed at the St. Petersburg Mining University can be used for heat treatment of the productive formation of high-viscosity oil, restoration of hydraulic connection between the formation and the well, increasing the oil recovery of formations with high-viscosity oil and well flow rate, as well as resuming the operation of unprofitable wells for oil, natural gas, fresh, mineral and thermal waters. [22]

The complex allows to perform technological operations of pulse-dose heat treatment and thermohydrodynamic influence. For this purpose, the complex includes a bottomhole zone heat treatment unit, a pump with an adjustable electric drive, a tank with boiler water, pump and compressor pipes, a water supply unit with a check valve. Automatic maintenance of the set technological parameters (voltage U, current I, boiler water flow rate q, pump speed ω) is provided by the control system.

Main elements of the device are shown in Figure 11.

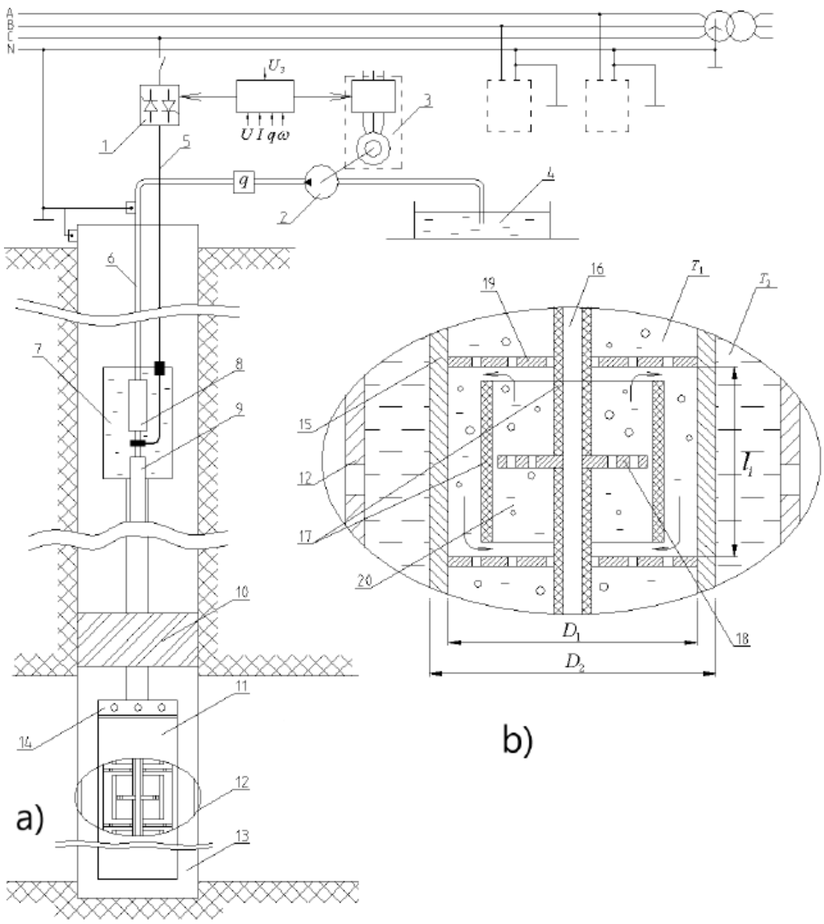

Figure 11: Main elements of the electrothermal complex

The device of the electrothermal complex, shown in Fig. 18 (a), consists of the current regulator 1, from which the power cable 5 goes to the steam generator, pump 2 with an adjustable electric drive 3. This pump is fed with boiler water from the tank 4 and by the pump-compressor pipe 6 gets to the steam generator through the dielectric insert 8, which contains an oil-filled input device 7 and a thermal conductor 9. The fluid then enters the steam generator, which is separated from the dielectric insert by a packer 10 to separate the two wellbore zones. The steam generator is at the level of the pay zone and is surrounded by formation fluid 13. The entire structure is separated from the medium by casing 12.

The design of the steam generator, shown in Fig. 18 (b), is a heater body 15 with a central current collector 16 and insulators 17, which are structurally necessary for circulation of the working fluid 20 through the central electrodes 18. Above the insulators there are case electrodes 19.

The operating principle of the complex is as follows:

After assembling the device and placing it in the area of productive formation the treated zone is isolated by heat-resistant packer 10. Through the current regulator 1 a current of 3-6 kV and frequency of 50 Hz is supplied through the power supply cable 5 to the disk electrodes 18, placed in the cavity of the heater body 15. After the current flows from the disk electrodes 18 through the liquid 20 to the body 15 of the heater, causing heating of the liquid 20, boiling and formation of steam. When the pressure in the steam zone reaches the opening pressure of the valves 14, steam through the outlet valves 14 enters the area of the borehole fluid, intensively heating it. In this case as the fluid flow 20 in the cavity of the heater body 15 is fed by the boiler water, transported from the tank 4 via a tube 6, equipped with a pump 2 and adjustable drive 3, along the tubing string, dielectric tube inserts 8 and the central tubular lead 9 in the lower cavity of the heater body 1. [23]

During the analysis of the technology, the following advantages were identified:

1) The technology does not require combustion of some of the extracted hydrocarbons, unlike the current technology of injection of the mineral.
2) Small capital expenditures for production. Thus, the technology can be used for the development of fields with low flow rates or for the introduction of secondary exploitation.
3) Electric steam generator allows generating in bottomhole zone steam with degree of dryness within 0.8-1.0, which is impossible when using traditional boiler equipment. This makes it possible to introduce an equal amount of thermal energy into the reservoir while injecting a smaller volume of steam by 15-20% as compared with conventional methods;
4) Simplicity in design;
5) There are no emissions into the atmosphere, i.e. the technology is environmentally friendly.

In a direct comparison of the current method of reservoir heating with the proposed electrothermal heating method, the main disadvantages of the former are:

- High capital costs;
- Heat losses in the steam pipeline and the well;
- Combustion of part of the produced oil (gas);
- Deterioration of the environmental situation;

Conclusions of chapter 3

1) Promising technology of extraction of high-viscosity oil is the use of modular mines. There are several variants of reservoir opening, but during the analysis the second method, which includes modular mines with opening by 1 vertical and 2 wells, was found to be the most preferable according to the sum of all factors.
2) The technology of downhole steam generation, despite its simple design, is more cost-effective, without compromising the pace of field development.
3) Both technologies have not previously been used in practice, which leads to the need to assess the level of safety when introducing modular mines in conjunction with electric steam generators.

4. Assessment of occupational risks using the proposed solutions

4.1. Principles of risk assessment

Risk – the combination of the probability of an event and its consequences. The term "risk" is usually used when there is a possibility of negative consequences.

The risk assessment procedure – a structured process of researching random processes to determine both the possibility of certain situations ending in the impact of hazards on the worker's body, and the significance of adverse consequences of such a realization.

After conducting this procedure, the employer must ensure that the following documents are available:

- Documented professional risk management procedure;
- List of identified hazardous and harmful production factors;
- Description of methods for assessing the level of occupational risks used in the workplace;
- List of measures to manage (exclude or reduce) occupational risks.

The purpose of occupational risk assessment is to predetermine the occurrence of events, assess the consequences of these events and the probability of their occurrence.

A risk level review of workers should be arranged whenever there are any changes in the work process: new equipment is commissioned, workplaces are moved to other premises, work organization is changed, new equipment and materials are used.

The first step is to create a risk assessment committee. Risk assessment can be done by an occupational safety specialist or occupational safety and health service, but it is more effective to create a commission of three to seven people. The composition of the commission is determined depending on the number of employees and the sphere of activity of the organization. [7]

This committee then investigates workplaces in order to identify hazards.Identification of hazards that could cause damage to the life or health of workers is the first and main stage of the risk management process. Identification is based on an analysis of the employee's workplace, work equipment, and work environment. Sources of harmful and dangerous production factors can be production or office equipment, technological operations, used raw materials and materials that the employee uses during work, etc. To identify hazards, it is necessary to identify all sources, situations, actions, or combinations thereof that may cause injury or impair the health of workers. [8]

The next step is to assess the levels of risk from the identified hazards. Most often the level of risk is determined on the basis of the probability of occurrence of an event and the degree of harm caused to the life and health of the employee. Assessment of risk levels is necessary to identify the highest priorities for their priority elimination, as well as to assess the subsequent methods of measures taken and their effectiveness.

It is necessary to assess not only the existing risks, but also the possible risks when new buildings, equipment, processes and workplaces are put into operation.

The employer determines the methods for assessing the level of occupational risks, taking into account the nature of its activities and the complexity of the operations performed. It is allowed to use different methods for assessing the level of occupational risks for different processes and operations.

Formation of the register of hazards and making adjustments is the last stage of the risk assessment. Depending on the level of risk, a list is made according to the results of the assessment for their subsequent elimination. To reduce the risks, it is necessary to produce measures to reduce the probability of occurrence of an event and reduce the degree of its impact.

There are several ways to reduce the risks for a particular employee:

- Automation of the process;
- Distribute the workload evenly among several employees;
- Implement new technologies, raw materials or materials that reduce hazards;
- Use more effective personal protective equipment.

The solutions to a particular task will depend on its essence, and there may be several for each task. The employer needs to choose the most effective of them. [14]

4.2. Hazard identification

To analyze the risk of accidents (injuries) and occupational diseases of the existing technology, first of all, it is necessary to analyze statistical data on accidents and injuries. The result of this analysis will establish the causes of the formation of accidents, as well as provide quantitative data on the distribution of the frequency of accidents and initiating events for further evaluation of risk factors.

Statistics show that from 2004 to 2014, there were 183 hazardous events at operating oil mines. These 183 events contain 82 explosions (45% of the total number of hazardous events), 66 fires (36% of the total), and 35 accidents involving the release of a hazardous substance (19%). The annual statistics of hazardous events are presented in Table 6:

Type of Accident	Number of dangerous events												
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total	
												pcs.	%
Explosion	6	11	10	5	5	6	9	16	6	3	5	82	45
Fire	2	5	10	14	6	5	4	1	5	6	8	66	36
Emission of harmful substances	1	2	1	3	2	2	3	3	7	5	6	35	19
Total	**9**	**18**	**21**	**22**	**13**	**13**	**16**	**20**	**18**	**14**	**19**	**183**	100

Table 5: Statistics of accidents at the Yaregskoye field in 2004-2014 years

Analysis of the results of technical investigations at the enterprise shows that the main causes of dangerous events are:

- Hazards associated with the failure and depressurization of technical devices;
- Personnel mistakes associated with violations of the requirements of the organization and production of hazardous and repair work;
- External hazards associated with uncontrolled mechanical effects on process equipment (discharge of atmospheric electricity, adverse weather conditions, earthquakes, etc.)
- Imperfect production technology and design flaws in technical devices;
- Violation of the technological process and maintenance of technical devices;

- The inability of personnel to identify and assess the real hazards of the workplace in a timely manner.

According to the document "Analysis of the causes and circumstances of accidents in "Yareganeft" in the period from 2003 to 2020 there were 29 cases of accidents.

The distribution of accidents by profession is shown in Fig. 12:

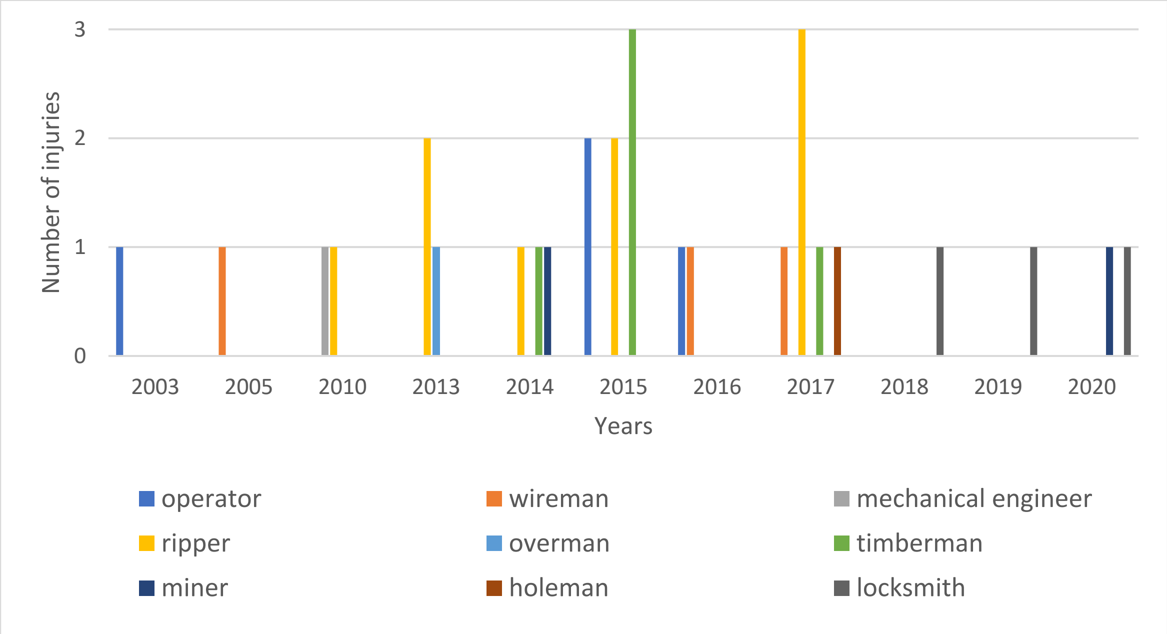

Figure 12: Dynamics of accidents by profession

According to these data, the most traumatic occupations are ripper and timberman. This is due to the fact that their workplaces are located in the most dangerous areas (tunneling section). According to statistics, these professions are the most dangerous. The most common causes of injury to one of these two professions are: violation of occupational health and safety requirements by the victim (e.g., being under an unsecured space or falling from a height) and a falling piece of rock mass.

This level of injury is the result of imperfect technological process, which needs to be improved. It is necessary to strictly control compliance with HSE rules or to minimize tunneling operations.

In spite of the accidents identified during the production period, other factors that may be the causes of accidents, but have not yet become them, should not be neglected.

Thus, pipelines operating under excess pressure, which transport above ground steam heated in boiler plants to the injection wells entail the following factors, which may contribute to the occurrence of emergency situations:

1) Handling an explosive flammable substance in the system;
2) Pressure vessels;
3) Corrosive activity of hazardous substances, which creates an additional risk of equipment depressurization;
4) The presence of an ignition source;
5) Presence of transitions of underground pipelines to above-ground pipelines, which are places of high stress concentration.
6) Additional risk of depressurization of process pipelines is also caused by operational factors, such as:
    - Frequency of inspection and repair;
    - Quality of preventive repair work.

These factors can be the source of an explosion and/or fire, resulting in the release of heated steam into the atmosphere, generating a shock wave that can collapse buildings and disable other equipment. In these scenarios, workers are exposed to hazards such as thermal radiation and overpressure.

Boiler plants where fuel is burned to heat water and then steam is a large hazardous production facility and, despite the high degree of equipment protection, has potential risks for employees working with this facility, which shown below:

- Current carrying parts of installations;
- Hot surfaces and open flames;
- Pressure vessels;
- Fans, boilers and other vibration generating units;
- High humidity and temperature of the working environment;
- Moving machines and mechanisms, moving parts of production equipment;
- Combustion products that can enter the atmosphere if filtering equipment fails or leaks;
- Work at height.

Occupational diseases, caused by the hazards of the working environment, is a slow and gradually progressing disease process with a chronic course. Due to the difficulty of timely detection of the disease, this parameter can affect the actions of the personnel both during the working shift and in emergency situations, which should also be taken into account in a comprehensive assessment of the risk of accidents (injuries). [10]

According to statistics, 170 cases of occupational diseases were registered in underground oil extraction from 2000 to 2016. The three main types of occupational diseases are:

- Vibrational disease of the upper extremities;
- Lumbar radiculopathy;
- Sensorineural hearing loss

Figure 13 showing the frequency ratios for a particular disease.

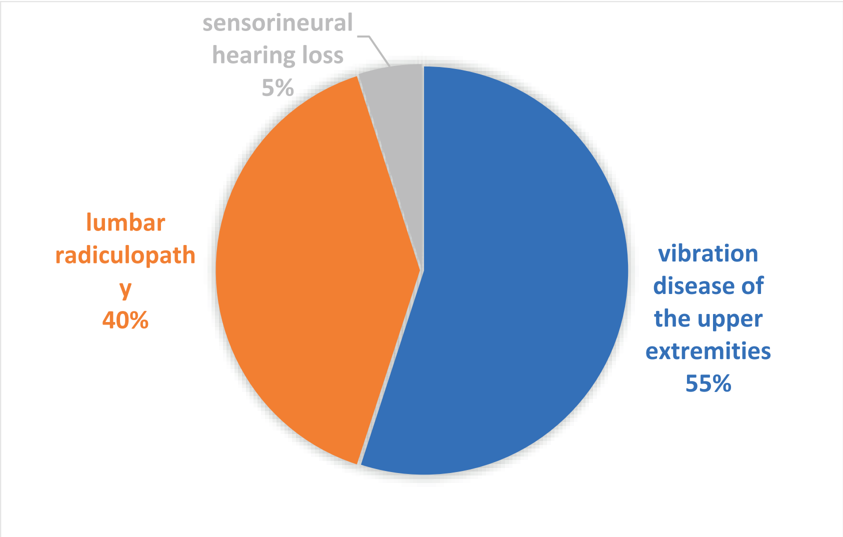

Figure 33: Proportional distribution of the incidence of detected occupational diseases

The source of these diseases is noise and vibration, which are hazardous and harmful industrial factors.

New technology involves a change in working conditions and aims to improve safety. Despite this, there is a need to identify the hazards of the new technology.

4.3. Methodology for assessing the level of occupational risk and risk of accidents

The proposed methodology combines both a quantitative assessment of factors that can be evaluated numerically and a qualitative assessment using matrix evaluation.

According to the number of occupational accidents, the individual risk of injury was determined according to the formula (1):

$$R_i = \frac{n_i}{N \cdot t} \ {}^{1}/_{year} \quad (1)$$

Where R_i – individual risk of hazards exposure for a given occupation for the period 2003-2020; n number of accidents detected in the i-profession over the time 2003-2020; N -Number of employees at risk of injury, is assumed to be 1,917 people – average number of underground personnel; t – the number of years with non-zero injuries, taken as 11.

The results of the calculations are presented in Table 7:

Profession	**Number of injures from 2003 to 2020**	**Individual injury risk R**
Operator	4	0,000190
Wireman	3	0,000142
Mechanical engineer	1	0,000047
Ripper	**9**	0,000427
Overman	1	0,000047
Timberman	**5**	0,000237
Miner	2	0,000095
Holeman	1	0,000047
Locksmith	3	0,000142

Table 6: Level of individual risk by occupation

Using the data from Table 7, the histogram in Fig. 22 shows the score distribution for the individual risk of injury. The limit values of the individual risk of underground personnel and their corresponding score are presented in Table 8.

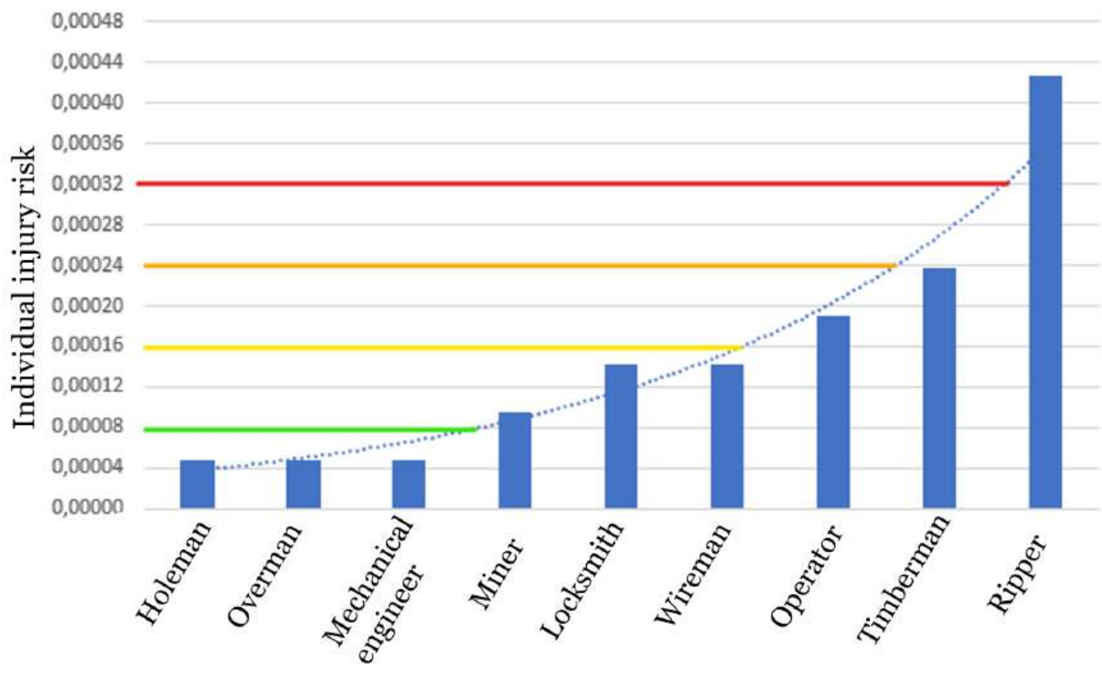

Figure 14: Distribution of injury risk zones

Zone (score)	Individual injury risk R
1	$<0,8 \cdot 10^{-4}$
2	$0,8 \cdot 10^{-4} - 1,6 \cdot 10^{-4}$
3	$1,6 \cdot 10^{-4} - 2,4 \cdot 10^{-4}$
4	$2,4 \cdot 10^{-4} - 3,2 \cdot 10^{-4}$
5	$>3,2 \cdot 10^{-4}$

Table 7: Boundary values of injury risk zones.

Thus, the most injury-prone occupation of underground personnel under the current mining technology is the ripper, who is assigned the fifth risk zone. It is also worth paying attention to the position of the timberman, which is located at the border value of the third and fourth levels of danger.

The use of expert evaluations is preferable in cases where it is impossible to conduct a full quantitative analysis due to the lack of sufficient information about the system under analysis. For this reason, the assessment of factors influencing the level of risk of ground personnel injuries will be performed using expert assessment using the developed matrix. The matrix consists of a 5-point horizontal scale, which evaluates the potential frequency of injury P (Table 9), and a 5-point vertical scale, which characterizes the degree of danger of this injury Q (Table 10).

Score of P	Probability	Description
1	Remote	The probability of occurrence is negligible.
2	Unlikely	The probability of occurrence remains low. Such conditions arise in isolated cases, but the chances are small.
3	Possible	The probability of occurrence is at an average level. The conditions for this may actually and unexpectedly arise.
4	Likely	The probability of occurrence is high. The conditions for this occur sufficiently regularly and/or over a period of time.
5	Certain	The probability of occurrence is very high. The conditions necessarily occur over a sufficiently long period of time. (usually under normal operating conditions).

Table 8: Description of the probability of risk occurrence scores

Score of Q	Probability	Description
1	Negligible	Low impact, first aid, minor injuries.
2	Low	No threat to life, no disability for more than 1 day.
3	Medium	There is a potential health risk, serious injury.
4	High	Group accidents with severe consequences; fatal accident.
5	Catastrophic	Several fatal accidents.

Table 9: Description of risk consequences scores

The multiplication of the two points will determine the final risk level. The boundary values of the risk levels are shown on the scale in Figure 23:

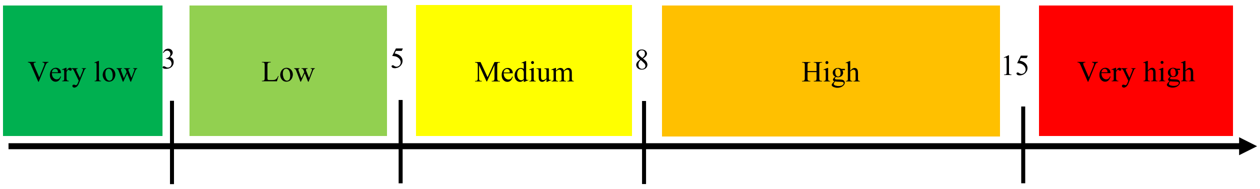

Figure 15: Scale of risk degrees

The final matrix is presented in Table 11:

Q \ P	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Table 10: Risk matrix

Employees associated with steam heating boiler equipment will be evaluated, as it is this aspect of the process that is changing with the application of new technology. This matrix evaluates such factors as overpressure, thermal radiation, reduced relative humidity, increased air temperature, mechanical injury, and toxic effects. This methodology also estimates the risk of accidents on the basis of statistical data presented earlier in Table 6.

The risk of acquiring an occupational disease is quantified. According to statistics, 170 cases of occupational diseases were registered in underground oil extraction during the period from 2000 to 2016.

Regression analysis of the relationship between the variables was performed using statistical data. The method was based on statistical data on occupational diseases received according to the results of medical examinations and received measurements of intensity of influence of harmful and dangerous production factors. These factors in this case are noise and vibration. As a result, the data presented in Table 12 were received:

Profession	Measured sound level, dBA	Probability of developing hearing loss after 20 years of work experience	Measured vibration level, dB	Probability of developing vibration disease after 20 years of work experience
Ripper	95,4	0,300	131,5	0,731
Operator of rock removing machines	91,3	0,096	129,3	0,306
Timberman	97	0,100	131,5	0,623
Drill runner	93,2	0,092	121,1	0,591
Oil production operator	91	0,078	103,4	0,130
Roadway worker	72,8	0,001	0,0	-

Table 11: Probability of developing an occupational disease in different professions

Next, the dependences of the risk of hearing loss and vibration pathology based on the level of influence of the factor in the workplace were obtained and trend lines were plotted. The results are presented in Fig. 16 and 17.

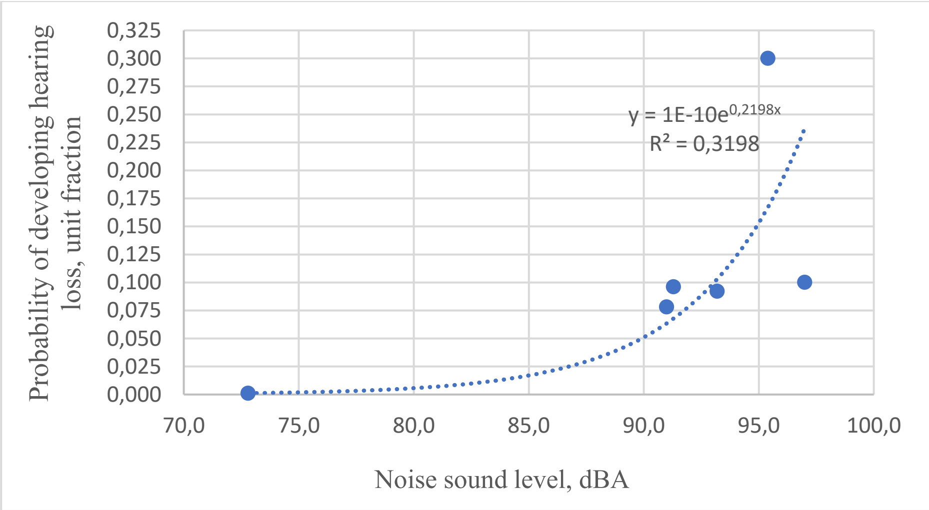

Figure 16: Probability of developing hearing loss after 20 years of work experience depending on the intensity of noise exposure

From the graph in Figure 25, it is concluded that the noise level after 92 dBA is critical, because the intensity of the increase in the probability of hearing loss development along the trend line begins to increase sharply.

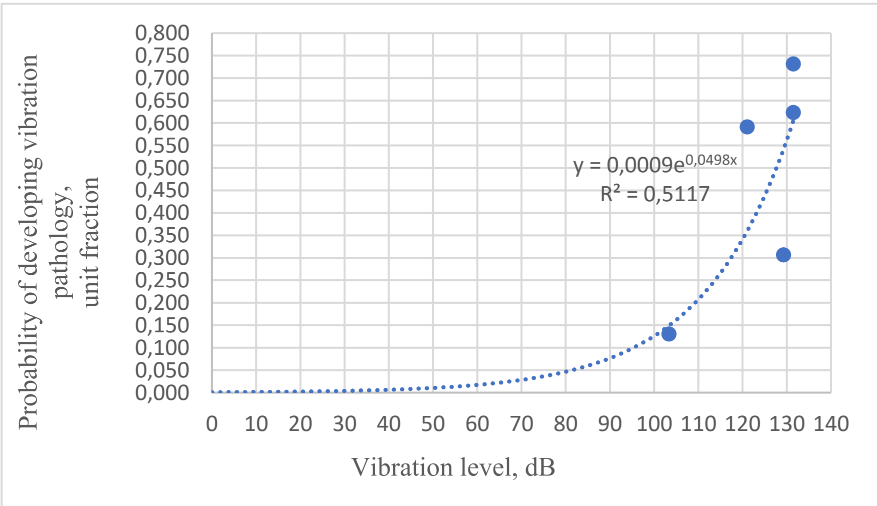

Figure 17: Probability of getting vibration pathology after 20 years of work experience depending on the intensity of vibration exposure

Fig. 25 shows a sharp increase in the risk of vibration pathology under the influence of vibration above the value of 120 dB.

The factors considered above significantly affect working conditions and may be the cause of the development of occupational diseases or injuries.

Based on the constructed dependencies after 20 years of experience for each of the diseases, as well as the dynamics of injuries, it is proposed to form a methodology of score risk assessment. The method of score risk assessment is a set of logical and mathematical procedures that allow to analyze the information and summarize the results of rational decision selection.

Figure 18 shows a graph with the accepted distribution zones of the scoring system in relation to the probability of developing a hearing loss.

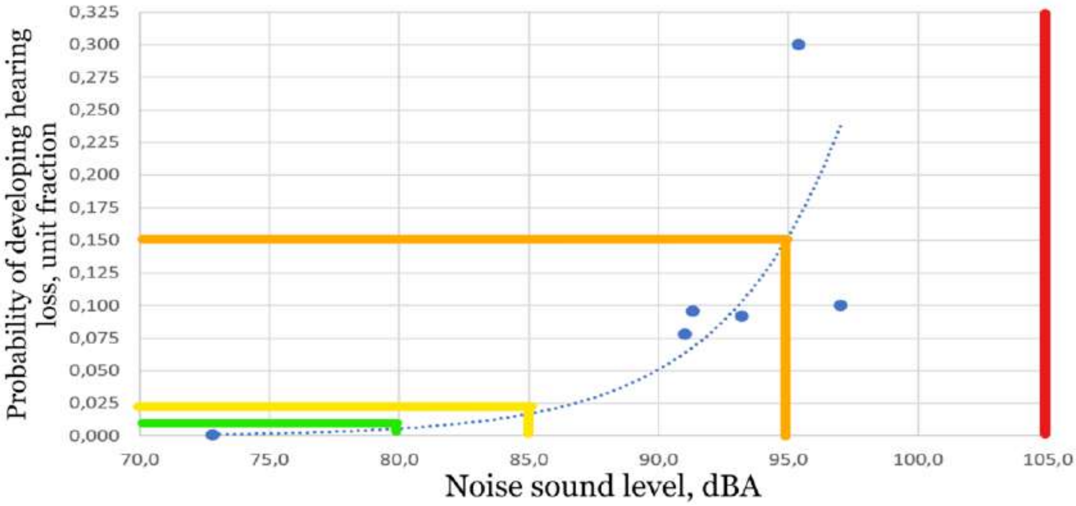

Figure 18: Location of noise hazard zones according to the probability of developing hearing loss

Boundary values for noise were taken on the basis of the class of working conditions in terms of noise level in dBA according to the laws of the Russian Federation. [16]

The graph shows a sharp rise in the probability of developing an occupational disease after the upper boundary of the first zone (90 dB). Most of the measurement points are concentrated at the border of the second and third zones. Based on the graph, the boundary values of each score are presented in Table 13:

Zone (score)	Probability of developing hearing loss after 20 years of work experience	Measured sound level, dBA	Class of working conditions
1	<0,004	<80	2
2	0,004-0,01	80-85	3.1
3	0,01-0,12	85-95	3.2
4	0,12-1,05	95-105	3.3
5	>1,05	>105	3.4

Table 12: Boundary values of noise intensity zones

Similarly, the distribution of the risk category of vibration pathology is carried out. The results are presented in Fig. 19.

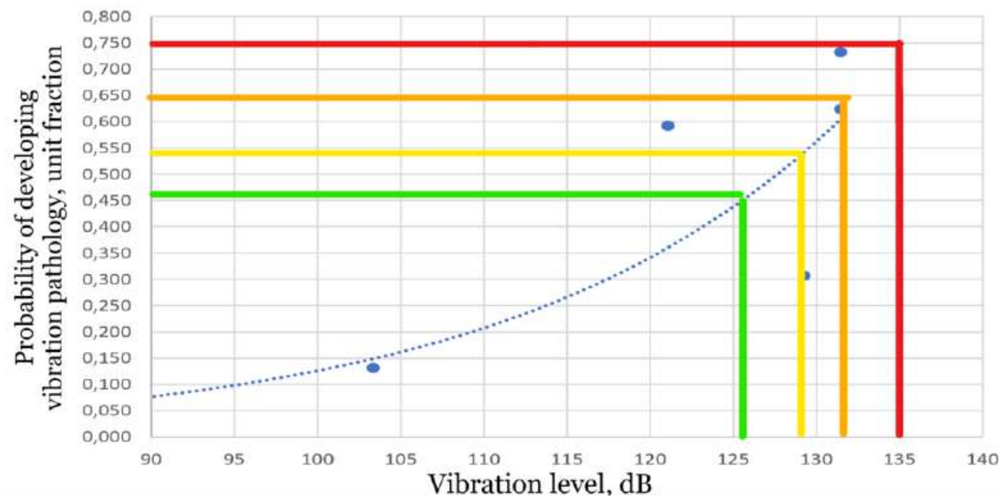

Figure 19: Location of vibration zones according to the probability of developing vibration pathology

The boundary values of vibration were taken on the basis of the class of working conditions according to the noise level in dB according to the laws of the Russian Federation. [16] Most workplaces belong to the third (harmful) class of working conditions. Despite the low level of vibration, many occupations have a high risk of acquiring a disease. According to the formula of the graph, the calculated limit values of each point are presented in Table 14:

Zone (score)	Probability of developing vibration disease after 20 years of work experience	Measured vibration level, dB	Class of working conditions
1	<0,48	<126	2
2	0,48-0,55	126-129	3.1
3	0,55-0,64	129-132	3.2
4	0,64-0,75	132-135	3.3
5	>0,75	>135	3.4

Table 13: Boundary values of vibration intensity zones

4.4. Assessing the level of occupational and accident risk

4.4.1. Risk of occupational diseases

Based on Fig. 27 and 28, presented in the methodology, the scores of probabilities of of hearing loss and vibration pathology are established. The level of influence of these factors does not change with the new technology. However, the risks are reduced by reducing the time of exposure to the harmful factor. The distribution of the scores is presented in Table 15:

Profession	Traditional mining technology		Proposed mining technology	
	Risk category for the development of hearing loss, score	**Risk category for the development of vibration pathology, score**	**Risk category for the development of hearing loss, score**	**Risk category for the development of vibration pathology, score**
Ripper	4	4	3	3
Operator of rock removing machines	3	3	2	2
Timberman	4	3	3	2
Drill runner	3	3	2	2
Oil Production Operator	3	1	2	1

Table 14: Score distribution of occupational disease risk

In terms of noise level, special attention should be paid to the workplace of the timberman and the ripper, where the noise level is incommensurably high and the probability of developing hearing loss is much higher than in other workplaces.

In terms of vibration levels, special attention should be paid to the occupations of the timberman, ripper, and drill rig operator, and measures should be taken to minimize the effects of vibration in these workplaces.

4.4.2. Risk of injury to underground personnel

The graph of the distribution of points and their corresponding occupations is shown in Figure 22.

The use of modular mines makes it possible to significantly reduce the tunneling work and thereby reduce the individual risk to the rippers and timbermen by reducing the accident frequency rate. According to rough estimates, the volume of mining and capital work in the modular development is estimated at 87.6 thousand m3 against 193 thousand m^3 using the current methodology of mining and capital work, which is 55% less.

A study of accidents related to the oil and gas operator has shown that most of them are related to the lack of time to get to the surface in an emergency situation. Modular mines significantly reduce the length of the evacuation route to the safe area, and therefore reduce the risk of injury. The work process of the remaining workplaces does not change, but they are located in permissible safe zones, i.e., the condition of the working environment at the workplaces must be monitored, but there is no need to change the working conditions.

The established points are presented in Table 16:

Profession	Traditional mining technology	Proposed mining technology
	Risk of injury, score	
Operator	5	4
Wireman	3	2
Mechanical engineer	3	2
Ripper	2	2
Overman	2	2
Timberman	2	2
Miner	1	1
Holeman	1	1

Table 15: Score distribution of the risk of injury with existing and proposed technology

4.4.3. Risk of injury for surface personnel

The traditional method of extraction consists in preparation of steam away from the place of direct extraction of the mineral. On this basis, the operating parameters of steam must be overestimated, so that steam reaches the injection well with acceptable physical and chemical characteristics. This implies powerful boiler plants with high overpressure and power consumption.

Generating steam directly downhole with downhole electric steam generators involves reducing the amount of time workers spend in the vicinity of and in contact with electrical equipment to generate steam. Moreover, because the fluid is heated directly in the wellbore, it requires significantly less power from electric generating units, so the severity of consequences from direct contact with live parts is reduced. This technology also replaces long steam pipelines in the field area with water pipelines, thus reducing the risks of thermal radiation and rupture, as well as lowering the operational requirements for the construction of these pipelines.

The absence of a large-sized boiler plant minimizes many hazardous and harmful production factors. With the current technology, the identified hazards and their risk assessment, according to matrix evaluation, are presented in Table 17:

Risk Factor	Probability of risk occurrence P	degree of risk damageQ	Risk Level	Category of rick
Falling from a height	2	3	6	Medium
Direct contact with live parts	2	4	8	Medium
Injury against a mechanical moving object	2	3	6	Medium
Effect of overpressure due to pressure vessel bursts	1	4	4	Low
Burns caused by touching objects of high temperature	3	3	9	High
Toxic effects due to bursting of hydrocarbon vessels	2	4	8	Medium
Unacceptable noise level	1	3	3	Low

Table 16: Risk assessment by the matrix method to the existing technology

When the technology changes, most of the factors above are at least reduced, and some are completely absent. A similar expert evaluation is presented in Table 18:

Risk Factor	Probability of risk occurrence P	degree of risk damageQ	Risk Level	Category of rick
Falling from a height	1	3	3	Low
Direct contact with live parts	1	3	3	Low
Injury against a mechanical moving object	1	1	1	Very low
Effect of overpressure due to pressure vessel bursts	1	2	2	Very low
Burns caused by touching objects of high temperature	1	1	1	Very low
Toxic effects due to bursting of hydrocarbon vessels	1	1	1	Very low
Unacceptable noise level	1	1	1	Very low

Table 17: Risk assessment by the matrix method to the proposed technology

The comparison on the polar risk map shown in Fig. 30, the hazard reduction for all risk factors is shown.

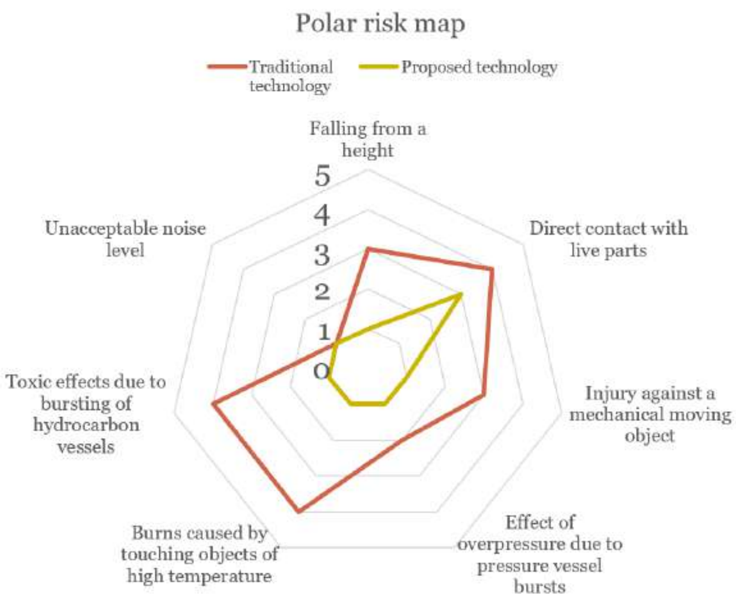

Figure 20: Polar map of risks of acquiring injuries of surface personnel

4.4.4. Industrial accident

Based on the statistics of dangerous events presented in Table 6, we can estimate the level of hazard frequency as the number of events divided by the time period. So, it turns out that on average at the Yaregskoye field occurs:

- 7.45 explosions per year, probability of occurrence - "Certain" (P=5)
- 6 fires per year, probability of occurrence - "Likely" (P=4)
- 3 emissions of hazardous substances per year, probability of occurrence - "Unlikely" (P=2)

In terms of danger, an explosion is the most adverse event, because in a short period of time a large amount of energy is released, which by a shock wave can spread over a large area and cause damage not only to employees, but also to nearby buildings and structures. For this reason, it is awarded the highest class of hazard effects - catastrophic (Q=5).

A fire in an underground mine is also a hazardous event that, due to environment saturated with hydrocarbons, can spread quickly and workers will have no way to localize it. Moreover, the process of combustion releases hazardous chemicals into the atmosphere, which, if PPE is not used in a timely manner, can cause fatal incidents. For example, on November 24, 2019, there was a fire at Yareganeft Mine No. 1, when 43 out of 45 employees managed to be evacuated. Five days later, two of the remaining miners were declared dead, and water was pumped into the mine to stop oil burning. Another case of fire that occurred in November 2020 at the Yaregskoye field formed in a sloping block of the third mine under construction. At the time of the fire there were 82 employees of Lukoil and contractor Neftegazmash, but only 80 employees of the mine managed to get out. Repeated group accidents with fatalities are the criterion, according to which this hazard is assigned the "Catastrophic" level of consequences.

Although the release of hazardous substances is extremely rare, it has more of an impact on environmental levels and less on the human body. Moreover, in workplaces where there is a possibility of inhalation of toxic substances for each employee is assumed a self-rescuer, which is the PPE of the respiratory organs for a certain period of time. Nevertheless, this factor can be one of the causes of fires, so it was decided to assign the release of hazardous substances to the level of consequences of exposure to hazards "Medium", thus the value of Q=3 points.

Based on the above, the results of the accident risk assessment, presented in Table 19.

Types of hazard events	Probability of risk occurrence P	degree of risk damage Q	Risk Level	Risk category
Explosion	5	5	25	Very high
Fire	4	5	20	Very high
Emission of harmful substances	2	3	6	Medium

Table 18: Assessment of the accident risk level of the traditional mining technology

According to the results, the conclusion about the increased accident rate in production, which must be eliminated by changing the technological process of production and improving industrial safety in the workplace.

Application of the proposed technology, combining developments in the field of modular mines and electric steam generators, will significantly reduce the severity of consequences by automating the process and reducing sinking operations. In cases of emergency, the usage of modular mines will make it possible to localize **fires** more effectively and eliminate them, while the existing technology in most cases forces a complete flooding of the underground section of the oil mine. Switching to wellbore steam generation significantly reduces fuel consumption, thereby reducing the volume of stored substances that could potentially be **released into the atmosphere** and have a toxic effect on the human body or become one of the factors of a potential fire/explosion. Refusal of the central boiler house and distribution of power generating devices over the area of the whole generation allows to reduce the risk of **explosions** and the danger of their consequences. Thus, based on the assessment of accident risks of the new technology according to the matrix methodology, the results are presented in Table 20:

Types of hazard events	Probability of risk occurrence P	degree of risk damage Q	Risk Level	Risk category
Explosion	2	3	6	Medium
Fire	4	2	8	Medium
Emission of harmful substances	1	2	2	Very low

Table 19: Assessment of the accident risk level of the proposed mining technology

Conclusions of chapter 4

1. The use of modular mines makes it possible to significantly reduce the tunneling work, the length of the evacuation route and thus reduce the individual risk of injury to underground miners.
2. Generation of steam directly in the borehole using downhole electric steam generators reduced duration of staying close and contact of workers with electrical equipment for steam generation, as well as reducing the severity of consequences from direct contact with live parts and the risks of heat radiation and rupture. So, the risk of accidents for surface personnel is also reduced.
3. In cases of an emergency situation, the use of modular mines will allow to localize fires more effectively and eliminate them, while the existing technology in most cases forces a complete flooding of the underground section of the oil mine. The absence of a central boiler house and the spread of power generating devices over the entire excavation area reduces the risk of explosions and the danger of their consequences.

Conclusion

In the master's thesis the level of industrial safety and labor protection of the current technology of oil production by mine method and complex technology of modular mines and downhole electric steam generators on the basis of assessment and management of accident risks, injuries and occupational risks was considered.

A statistical study of the influence of hazardous and harmful production factors on the personnel of oil mines was carried out. Based on practical and scientific-theoretical material, hazardous and harmful production factors for underground and surface personnel were identified. A method of risk assessment and forecasting was developed, taking into account the specifics of production. Based on the method, approbation was carried out under the conditions of an operating enterprise and practical recommendations for joint use of modular mine technologies and downhole electric steam generators, which allow improving industrial safety and labor protection in underground oil production, were developed.

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