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CLASSIFICATION AND RATING OF THE MAIN FACTORS INFLUENCED ON THE MINE WORKING STABILITY IN URANIUM MINES

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Abstract. The subject of the research is geomechanical processes in the rock massif during uranium mining and their impact on the stability of mine workings. The aim of the work is to assess the negative impact of mining enterprises on the environment, to classify the main factors influencing the stability of uranium mine workings and to determine the directions for increasing their stability. Research methods – analysis and generalization of the results of our own research, as well as data obtained by specialists from other scientific institutions in the mining sector. A classification of the impact of uranium ore mining and processing on the environment is developed. It is shown that the main role in the negative manifestations of mining production in the environment falls on geomechanical processes that provoke failures, subsidence and landslides of the earth's surface, as well as disruption of water circulation. To prevent or significantly reduce them, a number of modern effective means and technologies for mine working support are recommended. The main factors influencing the stability of workings are identified, and a block diagram of their interrelations is constructed. The classification is made, and the rating of the main elements of geological, geomechanical, technological and human factors influencing the stability of workings in uranium mines is determined. It is shown that in vertical shafts special attention should be concentrated on the areas of water inflows and zones of tectonic disturbances, and methods of non-destructive instrumental testing should be used for this purpose. In chambers, special attention should be paid to the justification of their sizes taking into account the rock physical and mechanical characteristics at the stage of preparing a block for its development. In development workings, especially with a long service life, it is necessary: at the stages of prospecting and design - to take into account data on tectonics, fracturing, stress-strain state of the massif, physical and mechanical properties of rocks, parameters of workings, their service life, type of support and depth of the deposit; at the driving stage – to observe strictly the technology and charts of support; during operation: to monitor regularly the state of the workings and supports and to control massif in order to identify hidden breaks and disintigrations. To reduce the costs of working support, it is recommended to use technologies based on synergetic effects in the rock massif.

Keywords: uranium deposits, mines, mine workings, sustainability, influencing factors, classification, rating, negative impact, prevention, recommendations.

1. Introduction

The energy security of our country depends significantly on the import of natural gas, and in recent years, on coal. In addition, the world has faced major environmental problems with the use of coal. Therefore, over time, we will also be forced to abandon it due to exorbitant CO_2 emissions. Even with the development of alternative sources, such as the sun or wind, stable sources will still be needed, among which the best is nuclear energy. Unfortunately, in this area we are still dependent on the import of raw materials. Therefore, by mining our own uranium, we must enter a closed cycle within Ukraine, thereby ensuring its energy security. This is realistic, since our confirmed uranium reserves of 23 explored deposits amount to more than 200 thousand tons. According to this indicator, we are among the top ten countries in the world [1].

The benefits of uranium fuel are obvious. But the harm that accompanies the entire technological process of its production also causes great concern. Although the opinions of experts on this issue are ambiguous and, in most cases, declarative. Therefore, they require careful scientific justification. But the fact is that the territories adjacent to all mining enterprises are considered zones of environmental and man-made danger [2–5].

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In the advanced countries of the world, the method of borehole underground leaching is mainly used for uranium mining. Its idea is that an alkaline solution is pumped through several boreholes drilled into the ore body. After that, another borehole is drilled in the center and the solution saturated with uranium salts is pumped to the surface through it. But Ukrainian uranium mines operate using the old traditional technology. The level of their danger depends on a number of natural and man-made factors. In particular, the depth of the deposit, its tectonic-structural structure, rock pressure, technologies of driving, extraction and support of mine workings, the stress-strain state of the "massif – working – support" system, etc. The most significant of them is the stability of mine workings. This characteristic has a great impact on the economic performance of the mine and, according to statistics, on the number of accidents and the safety of miners. Imperfect technology for developing deposits and supporting (or backfilling) workings also leads to subsidence of the earth's surface, the formation of sinkholes and soil erosion, and accelerates the processes of pollution of underground and surface waters. The scale of these manifestations is enormous. According to official reports of the Ministry of Environmental Protection and Natural Resources, in recent decades, a catastrophic environmental situation has developed at the uranium mines of Ukraine [6].

The aim of the work is to assess the negative impact of mining enterprises on the environment, to classify the main factors influencing the stability of uranium mining mines, and to determine the directions for increasing their stability.

2. Methods

The work uses the analysis and generalization of the results of our own research, as well as data obtained by scientists and specialists of the State Enterprise "UkrNDPRI Promtekhnolohii" (Zhovti Vody), the Kryvyi Rih National University and the Dnipro University of Technology [7–11]. To determine the negative effects of underground uranium mining, indicators were used that form the basis of the world and European classifications of the impact of the mining complex on elements of the natural environment [12–16]. Based on the analysis of publications, the main emphasis is placed on the following negative impacts:

- geomechanical changes due to the construction of mines and subsidence of the earth's surface due to the formation of underground cavities;
- hydrological changes due to the drainage effect of mining operations on the water regime of the territory and deformation of the earth's surface as a result of pumping out surface and groundwater;
- chemical changes due to the discharge of saline and polluted industrial wastewater into surface watercourses and reservoirs, the impact of toxic components contained in waste dumps on the quality of soil and surface and groundwater.

The methodology we have developed for assessing the impact of negative factors on the current state of a certain element of the uranium ore mining complex is based on taking into account the statistical characteristics of the basic factors. Unlike known works in this direction using the Monte Carlo method [17–20], our developed algorithm involves simultaneous consideration of variations of several factors and includes a number of sequential stages.

At the first stage, an analytical dependence is established between the value of the output parameter and the input parameters.

At the second stage, two groups of input data (parameters) are determined:

- natural, the values of which do not depend on human activity;
- technological, which are determined by the project.

In each of the specified data groups, there may be certain deviations from the average value. In the parameters determined by the natural properties of the rock massif, this is mainly due to the variability of the geoenvironment indicators. Additional variation in the numerical values of the parameters is also introduced by errors in their determination in laboratory or mine conditions. This is especially true for values determined by non-destructive testing methods using correlation dependencies. The design parameters of an underground structure cannot be reproduced absolutely accurately either. Depending on the construction technology of the working, its geometric dimensions also fluctuate around a certain average value. The normal distribution of the input data array is assumed by default.

The third stage determines the number of computational experiments to determine the expected parameter for a random combination of input data values. Typically, this number should be several thousand.

At the fourth stage, the parameters of the random (pseudo-random) number generators are set. Each of the generators works with a sample of a specific input parameter. The sample size is determined by the number of computational experiments. The data distribution in the sample is assumed to be normal and the distribution parameters correspond to the experimental data. Each of the sample elements has an individual serial number. In the process of calculations, the sample size does not change, that is, we are talking about samples with return.

At the fifth stage, a computational experiment is conducted. In each calculation cycle, a random value for each of the input parameters is selected and the result is calculated. In more detail, this occurs as follows. A sample generator with a uniform distribution produces a random number, which is used to determine the random value of the first input parameter. In the next step, a random number is generated in a similar way, which is used to determine the random value of the second parameter. The process of forming a set of input data ends when the random value of the last input parameter with a data spread is determined. The first value of the output parameter is calculated from this random set of inputs. Then the entire described cycle is repeated until the planned number of computational experiments is completed.

At the sixth stage, the obtained sample of input values of the parameter is analyzed, which in a certain way characterizes the state of the underground structure or the surrounding geoenvironment. The data scatter may differ from normal. The entire data set is divided into ranges, each of which defines a certain category of the state. At this stage, the most probable result is determined, and the risks of one or more key parameters exceeding the permissible limits are assessed.

The assessment of impact factors was carried out on a five-point scale. Zero indicates no impact. One indicates minimal, and five indicates maximum impact within the factors and objects listed in the tables. That is, the assessment is relative, since it is impossible to compare indicators that have different units of measurement and are not only economic, but also social in nature.

3. Results and discussion

3.1 Example of assessing the stability of a mine working

For illustration purposes, the application of the above-described algorithm for assessing the stability of a real object – the haulage roadway in the "Nova" mine of the "Shid-Ruda" enterprise (Zhovti Vody) – is given. The calculation formula for assessing stability is taken from the work [21] and has the form:

$$\eta = \frac{0.1 k \cdot \rho \cdot g \cdot H}{\sigma_c}, \qquad (1)$$

where η is a dimensionless omplex index of the stress state of rocks; k is the stress concentration coefficient; ρ is the average density of the overlying rocks; g is the acceleration of gravity; H is the depth of the mining operation; σ_c is the uniaxial compressive strength of the rocks in the contour zone.

In this calculation, the constants are the acceleration of gravity (9.81 m/s^2) and the depth of occurrence (535 m). Information about the quantities, the values of which are limited to a certain range and have a probabilistic nature, is given in Table 1.

Table 1 – Degree of uncertainty of input data

Parameter and designation	Dimension of the parameter	Mathematical expectation	Mean standard deviation
Stress concentration coefficient k	Dimensionless	1.10	0.12
Density of overburden ρ	kg/m^3	2800	150
Uniaxial compressive strength σ_c	Pa	14.2×10^6	1.7×10^6

Random numbers with uniform distribution in a given range are generated using an option built into the JavaScript programming language [22]. Based on the resulting array, a secondary array of normally distributed random numbers is created using the Box-Muller transform [23].

The final result of the computational experiment is illustrated by the diagram presented in Fig. 1.

The criteria for assessing the state of the working, according to the value of the parameter η and the degree of fracturing, are given in Table 2.

In accordance with [21], the degree of fracturing is estimated by the number of disintegration cracks per meter of exposure according to Table 3.

According to the results of the geological survey, the fracturing of the rock massif in the contour zone of the haulage roadway can be assessed as average. Taking this into account, the probability of each of the possible states of the mining working was calculated. The corresponding results are presented in Table 4.

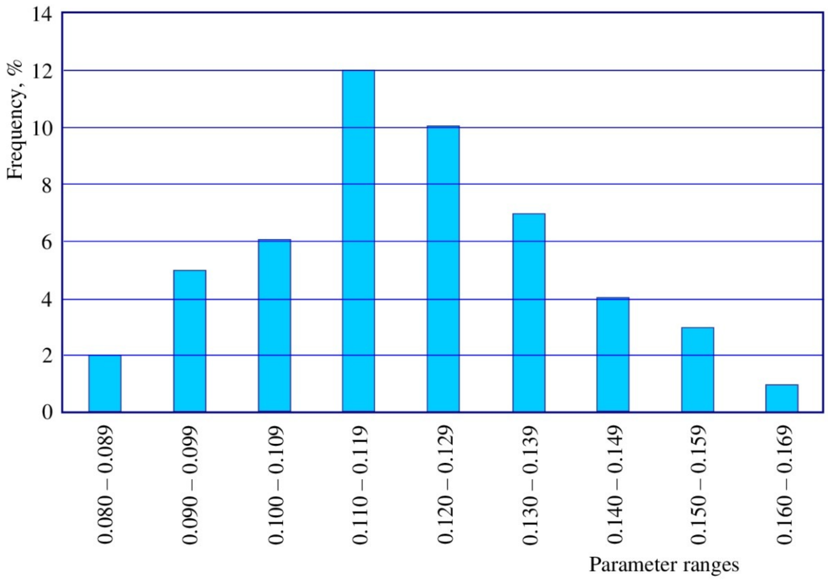

Figure 1 – Distribution of values of the dimensionless parameter η according to the results of the computational experiment

Table 2 – Criteria for assessing the state of a mine working based on the value of the complex indicator of the stress state of rocks and the degree of fracturing

Value of parameter η	Fracturing of rocks	Stability of workings
Less 0.120	Weak and medium	Extremely resistant
From 0.120 to 0.150	Weak and medium	Resistant
	Intense	Average resistant
Over 0.150	Weak and medium	Average resistant
	Intense	Low resistant

Table 3 – Criteria for assessing the fracturing of a rock massif

Number of cracks per 1 m of exposure	Rock Fracture
Up to 7	Weak
From 7 to 15	Medium
More than 15	Intense

Table 4 – Probability of different categories of mine working stability

Range of η values	Mine working stability	Probability
Less than 0.120	Extremely stable	0.50
From 0.120 to 0.150	Stable	0.48
Above 0.150	Moderate stability	0.02

The obtained results indicate practically identical probabilities of classifying a mine working as extremely stable and stable categories. The average stability of a working does not pose an immediate threat during its operation. Therefore, with a confidence probability of 0.95, it can be accepted for operation without additional engineering measures.

The work of the support is divided into five classes (Table 5).

Table 5 – Stability and operating conditions of mine workings support

Class of work of the support	Contour offset, mm	State and form of stability loss	Operating mode of the support
I	< 30	Extremely stable, stable	Without loading
II	30–70	Stable, arch formation	Joint work of support and rock massif
III	70–1200	Medium stable, formation of inelastic deformation zones	
IV			
V	> 1200	Unstable, viscous flow	-

Our observations at the “Nova” mine of “Shid-Ruda” LTD, as well as the data of "UkrNDPRI Promtekhnolohii" obtained at the mines of the "ShidHZK" State Enterprise, indicate that the work of the support at uranium mining mines belongs to classes I and II. The exception is the zones of geological disturbances, where processes characteristic of class III support work may occur.

3.2. Classification of the impact of uranium ore mining and processing on the environment

The classification is based on the results of our own research at mining enterprises in the Western and Central Donbas, Krivbas, Zhovti Vody and western regions of Ukraine, with the use of Internet information [24–28]. The proposed assessment of the negative impacts of production on the environment is presented in Table 6.

The table shows that, according to the factor of negative impact on the environment (anti-rating), mining enterprises are in the following order: uranium mines; quarries for the extraction of ore and construction raw materials; coal mines; iron ore mines and enrichment factories; mines for the extraction of non-metallic raw materials.

As for the impact factors themselves, they can be combined into three groups:

- very significant (failures, subsidence and landslides of the earth's surface, disruption of water circulation and contamination of aquifers, loss of agricultural land, presence of dumps and tailings ponds);
- significant (dust and toxic air pollution and seismic impact on industrial and civil structures);
- moderate (radiation contamination of territories, intensification of radon emissions and other hazardous gases).

From the point of view of the physics of phenomena that lead to negative manifestations of mining production in the environment, geomechanical processes play the main role. This is the formation of cracks and destruction of rock massifs, which provoke the occurrence of sinkholes, subsidence and landslides of the earth's surface, as well as disruption of water circulation and other related negative effects.

Table 6 – Classification and assessment of negative impacts of mining enterprises on the environment

Impact factor	Negativity indicator						Numerical assessment of the impact factor
	Uranium mines	Coal mines	Mines for the extraction of non-metallic raw materials	Mines for the extraction of iron ore	Quarries for the extraction of ore and construction raw materials	Enrichment factories	
Sinkholes, subsidence and landslides	3	4	5	3	2	1	18
Disruption of water circulation and contamination of aquifers	3	3	2	3	4	3	18
Presence of dumps and tailings ponds	3	4	1	3	1	5	17
Dust and toxic air pollution	3	2	1	2	4	2	14
Loss of agricultural land	2	2	3	2	4	4	17
Radiation contamination of territories	4	1	0	1	1	1	8
Seismic impact on industrial and civil structures	3	1	1	3	5	1	14
Intensification of hazardous gas emissions	2	2	1	1	1	1	8
Sum of negatives	**23**	**19**	**14**	**18**	**22**	**18**	**-**

In order to prevent negative manifestations of geomechanical processes or to significantly reduce them, we recommend introducing modern and more effective means and technologies for supporting mine workings in uranium mining mines. In particular, to reduce and slow down the processes of crack formation, subsidence of rock massifs and sinkholes on the earth's surface and disruption of aquifers, as well as to solve the problems of tailings impoundments, it is necessary to:

- reduce the delay between the process of erecting the support and the excavation;
- replace the rod reinforced concrete rock bolt with steel-polymer one;
- introduce plugging technologies in areas with expected increased water inflow;
- support areas of tectonic faults with metal frame support;
- introduce the technology of mandatory backfilling of chambers, using rock from dumps and tailings storage facilities as backfill material (traditionally, cement, blast furnace slag and sand were used for this, which were brought into the mine from newly formed quarries, where cavities were newly formed);
- oblige the enterprises that are engaged in the extraction of raw materials and know that other construction or rare earth components will be found there, to include their mandatory processing in the work program.

3.3. Classification and rating of factors influencing the stability of uranium mine workings

Traditionally, when mining uranium ores, the following development systems are used depending on the methods of rock pressure control: with natural support of open face, with caving of ore and surrounding rocks, and with artificial support of the open face. The technology of supporting mine workings in uranium mining mines in Ukraine has been regulated by three documents for many years. These are the "Instructions for determining rock stability when driving mine workings in conditions of uranium deposits of the "SkhidHZK", "Recommendations on selecting support for junctions of mine workings backfilled during winning operations " and the standard STP 39-73 "Technology for horizontal mine working construction in the main and intermediate horizons". According to these documents, even sections of mine workings driven through the hard rocks are subject to selective reinforcement with concrete rock bolts and continuous shotcreting. The options for reinforcing workings of the operating mines of the State Enterprise "SkhidHZK" are presented in Fig. 2.

a.

b.

c.

d.

a – unsecured section; b – workings with shotcrete; c, d – continuous combined support

Figure 2 – Options for supporting workings in operating mines of the State Enterprise "SkhidHZK

Each of the mining systems has drawbacks that can be eliminated or significantly reduced by using the results of modern researches in the field of geomechanics [29–32]. We are talking about the phenomenon of zonal disintegration of the rock mass and the associated effect of its self-organization. One of the manifestations of such a synergetic effect is formation of an arch around the mine working, which provides additional stability for the working due to a decrease of stress concentration in individual sections of the contour. These processes contribute to the growth of long-term stability of workings and reduction of costs for their support.

Synergetic effects in the rock massif create zones of natural equilibrium around the workings. This a priori necessitates constructing the mine workings with a cross-section shape close to natural one formed under the action of rock pressure forces. Depending on the mining and geological conditions, such a shape can be a circle, a horseshoe, an ellipse or a semi-ellipse, an arch or a semi-arch. The shape coefficient is determined by the ratio of the vertical and horizontal components of the massif stresses on the mine workings contour. Calculations and experience of implementing such an innovative technology for mine workings support showed that its use reduces costs by 40–60 %.

A number of works indicate the possibility of abandoning the support of mine workings constructed in stable and very stable rocks. And in case of their long-term operation, it is proposed to use just isolating, enclosing or combined support. However, the experience of mining uranium and other ore deposits indicates that even workings driven in rocks with a stability coefficient greater than one require selective or continuous support. This is due, first of all, to the "Safety Rules ...", the main purpose of which is to secure lives and health of workers and prevent accidents.

When selecting the type and parameters of the support, it is important to meet a number of conditions. First of all, assess the stability of the mine working by determining the pressure on the support and the nature of the formation of the stress-strain state of the rock massif around the working. The pressure on the support can be determined either by the method of structural mechanics through a given load, or through a given deformation, which is the result of the interaction of the support with the wall rocks. Secondly, it is necessary to calculate the stability coefficient of the mine working, for example, by determining it through the ratio of rock strength and shear stress acting in the roof and sisdes of the working. Thirdly, to take into account the long-term stability coefficient depending on the service life of the working. It is also necessary to consider whether the working is subject to technological collapse in the future. In this case, for example, it is necessary to replace concrete rock bolts with metal-plastic ones and pre-apply a layer of shotcrete to the contour to level it (Fig. 2 a, b).

The results of the research showed that depending on the class of rock stability in mine workings, the following types of support should be used: Class I – no support, shotcrete, rock bolt; Class II – shotcrete, rock bolt with mesh; Class III – rock bolt with shotcrete, metal; Class IV – metal, rock bolt with reinforced shotcrete; Class V – arch support, flexible, extended rock bolt and reinforced shotcrete.

The stability of chambers and long workings of uranium mining mines is most influenced by three factors: the geomechanics of the system "rock massif – working – support or protective structure", the geology of the deposit and mining technology.

Geomechanical factors include the physical and mechanical properties of rocks and ores, as well as the stress-strain state of the massif. In particular, initial and additional stresses arising under the action of gravity and during mining operations. They disrupt the continuity of the environment, which leads to a redistribution of stress components by their magnitude and location of concentration.

The main geological factors of influence are the depth of development of the deposit, the structural features of the rock massif, the angle of incidence and thickness of the ore body, the hydrogeological and tectonophysical characteristics of the deposit.

Mining and technical factors (and their derivatives) include the mineral development system, the technology of driving workings and forming chambers, the geometric parameters of extended workings and chambers, the service life, the technology of fastening mine workings, the dynamics of the progress of winning operations and the sequence of working chambers, and the physical and mechanical properties of the backfill material.

The human factor is of significant importance, determining the quality of mining operations and their justified sequence. It is also necessary to point out the mutual influence of both groups of factors and their components. Fig. 3 shows a block diagram of the interrelations of factors influencing the stability of uranium mining mines.

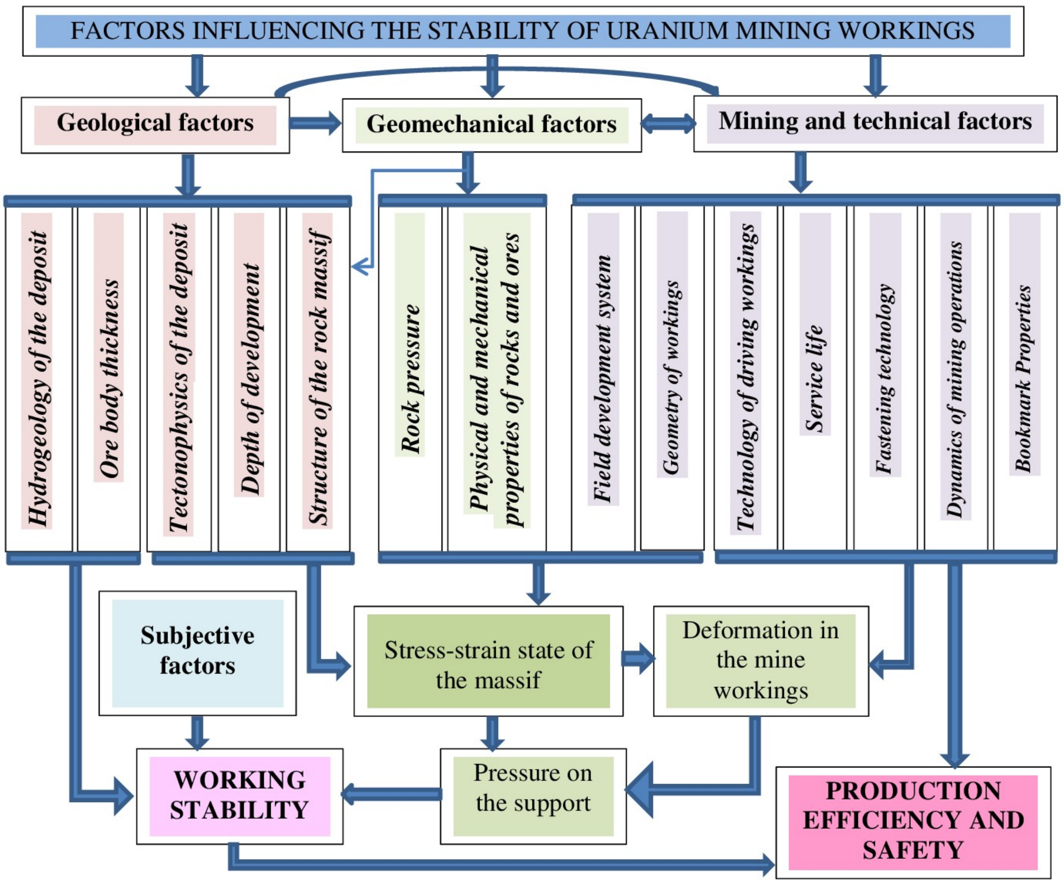

Figure 3 – Block diagram of the relationships between factors influencing the stability of uranium mining mines

According to the block diagram, geological, geomechanical and mining-technical factors that form the basis of influence on the stability of workings are also interconnected. Primary geological factors determine or influence geomechanics and mining production both directly and indirectly. At the same time, they themselves are almost not subject to reverse influence, except for fracturing, which changes depending on deformation processes in the massif caused by technical and technological measures for driving and mining the mineral, as well as on working support. But in this case, we should talk about technogenic fracturing, not structural. The main characteristic that determines the stability of workings is the stress-strain state and deformations of the massif depend on almost all components of geological, geomechanical and mining-technical factors.

Natural hydrogeology and the thickness of the ore body have almost no direct effect on the stress-strain state. However, indirectly, due to the geometric parameters of the workings, they can have a partial effect on their stability. The final result of the action of stresses is an increase in pressure on the support of the working and the marginal part of the massif. This, if the critical value is exceeded, will lead to a loss of stability and destruction of the working, negative consequences of an economic and social nature.

Table 7 presents a proposed assessment of the influence of some elements of the listed factors on the stability of mine workings during underground mining of uranium ores.

Table 7 – Assessment of the main elements of impact on the stability of mine workings during underground mining of uranium ores

Element of the impact factor	Impact indicator on the stability of workings					
	Mine shafts	Chamber mining:		Development mine workings (side):		
		side	roof	hanging	laying	roof
Geological factors						
Depth of development	3	2	3	3	2	3
Fracturing of the massif	3	3	3	4	2	4
Presence of tectonics	4	2	3	4	3	4
Deposit dip angle	1	2	2	3	2	2
Geomechanical factors						
Rock strength	2	3	3	4	2	4
Rock elasticity	2	2	3	3	2	3
Stressed state	3	4	4	5	3	5
Mixed geological and geomechanical factors						
Watering	4	2	2	2	3	2
Initial pressure	2	2	2	3	2	4
Mining and technical factors						
Penetration technology	1	2	2	3	2	3
Fastening technology	3	2	3	4	3	4
Service life	3	1	1	4	2	4
Subjective factors						
Labor discipline	2	1	2	3	2	3
Psycho-emotional state	1	1	2	2	1	2

The assessment is made by a five-point scale. 1 means virtually no impact, 2 – insignificant impact, 3 – average impact, 4 – significant impact, 5 – very significant (close to emergency) impact. The assessment is made for the existing conditions of uranium mining in Ukraine at the Ingulskaya, Smolinskaya and Novokostyantynovskaya mines of the “SkhidHZK” State Enterprise.

If we proceed from the position on the normal state and permissibility of operation up to level 3 (average impact) without special requirements regarding monitoring the technical state of workings, then we can draw several of the following conclusions.

In vertical shafts, along with the technical inspection regulated by safety rules, special attention should be focused on areas of water inflows and zones of tectonic disturbances (if any). For this purpose, in addition to visual assessment, non-destructive instrumental testing methods should be used. Namely:

- vibroacoustic methods of monitoring crack formation and disintegration of concrete, as well as the presence of cavities in the rock massif;
- ultrasonic method of testing (US) the strength of concrete;
- method of pulsed electromagnetic radiation of rocks (PERR) in the variant of longitudinal profiling of the shaft.

Regarding the chambers, special attention should be paid to the justification of their sizes with clarification and consideration in the calculations of the physical and mechanical characteristics of rocks. It is advisable to control the characteristics by sampling and laboratory testing at the stage of preparing the block for its development. Alternatively, express technology can be used to determine the strength of ore and rock directly in the mine using the impact pulse method.

With regard to the stability of development workings, especially those with a long service life, a number of additional requirements must be met to ensure their normal operation. Namely:

- at the stage of geological survey work: to obtain, and at the design stage, to take into account data on the presence of tectonic faults and fracturing of the rock massif;
- at the design stage: to pay special attention to data on the physical and mechanical properties of rocks and modeling the stress-strain state depending on the parameters of the workings, type of support, depth of development, planned service life, etc.;
- at the driving stage: to adhere strictly to the support setting technology and charts of supports in the workings;
- during the operation: to monitor regularly the state of the workings and support, and also to perform vibroacoustic control in order to identify hidden breaks and disintegrations with their further elimination.

The rating (on a five-point scale) of the impact of natural, man-made and human factors on the mine working stability in uranium mines (in decreasing order of the total impact indicator) is given in Table 8.

For clarity, the impact rating values are highlighted in color. Namely: green indicates insignificant impact; yellow indicates moderate impact; brown indicates significant impact requiring special measures.

Table 8 – Rating of the influence of natural, man-made and human factors on the mine working stability in uranium mines

Factor or its element	Average value of the impact assessment indicator			
	Mine shafts	Chambers	Development workings	In general
Rating of impact factors				
Geomechanical	2.33	2.50	3.44	3.17
Geological	2.75	2.50	3.00	2.79
Mining and technical	2.33	1.83	3.22	2.61
Geological and geomechanical	3.00	1.83	2.67	2.50
Human	1.50	1.50	2.17	1.83
Rating of elements of impact factors				
Stresses and strains	3.00	4.00	4.33	4.00
Tectonics of the massif	4.00	2.50	3.67	3.33
Fracturing	3.00	3.00	3.33	3.17
Fastening technology	3.00	2.50	3.67	3.17
Rock strength	2.00	3.00	3.33	3.00
Depth of development	3.00	2.50	2.67	2.67
Initial pressure	2.00	2.00	3.00	2.50
Watering	4.00	2.00	2.33	2.50
Rock elasticity	2.00	2.50	2.67	2.50
Operating life	3.00	1.00	3.33	2.50
Drilling technology	1.00	2.00	2.67	2.17
Labor discipline	2.00	1.50	2.67	2.17
Rock dip angle	1.00	2.00	2.33	2.00

4. Conclusions

A methodology was developed for assessing the impact of negative factors on the current state of elements of uranium ore mining complex based on accounting variations in several statistical characteristics of basic factors.

It was established that the values of the stability coefficient and the recorded displacements of the contour of mine workings in uranium mines correspond to the work of the support in the range from the 1st to the 3rd class. That is, the support works with an insignificant load, or its joint work with the rock massif is observed resulting in formation of an arch and other manifestations of synergetic effects. At the same time, the introduction of the support technologies based on the self-organization effects in the massif makes it possible to reduce costs for the mine working support by almost 50 %.

A classification was developed, and a rating was determined for natural, man-made and human factors influencing the stability of uranium mine workings. It is shown that the natural and man-made geomechanical factor and its element "stress and strain – have" a predominant effect on the mine working stability. At the same time, geology of the deposit, except for areas of tectonic disturbances, has almost no direct effect on the stress-strain state, but may indirectly, due to the geometric parameters of the workings, have a partial effect on their stability.

Based on the purpose of mine workings, it is shown that in vertical shafts, special attention should be focused on areas of water inflows and zones of tectonic disturbances (if any). To this end, non-destructive instrumental testing methods should be used. In chambers, special attention should be paid to the justification of their sizes with clarification and consideration of the rock physical and mechanical properties. It is advisable to do this by sampling and laboratory testing at the stage of preparing a block for its development. In development workings, especially with a long service life, at the stage of prospecting and design works, it is necessary to take into account the presence of tectonic disturbances, fracturing of the massif, physical and mechanical properties of rocks and the stress-strain state depending on the parameters of the workings, type of support, depth and service life. At the driving stage, it is necessary to adhere strictly to the technology and charts of supports, and during operation – to monitor regularly the state of the workings and support, and also to control the massif to identify hidden breaks and disintigration.

Conflict of interest

Authors state no conflict of interest.

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КЛАСИФІКАЦІЯ ТА РЕЙТИНГОВА ОЦІНКА ОСНОВНИХ ФАКТОРІВ ВПЛИВУ НА СТІЙКІСТЬ ВИРОБОК УРАНОДОБУВНИХ ШАХТ

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Анотація. Предмет досліджень – геомеханічні і інші процеси в породному масиві при видобутку урану та стійкість гірничих виробок. Мета роботи – класифікація і рейтингова оцінка основних факторів впливу на стійкість виробок уранодобувних шахт та визначення напрямків запобігання їх негативного впливу на навколишнє середовище. Методи досліджень - аналіз і узагальнення результатів власних досліджень, а також даних, що отримані фахівцями інших наукових установ гірничого профілю. Виконано класифікацію впливів виробництва з видобутку та переробки уранових руд на природне середовище. Показано, що в негативних проявах гірничого виробництва у навколишньому середовищі основну роль відіграють геомеханічні процеси, які провокують провали, просідання і зсуви земної поверхні, а також порушення водообігу. Для їх запобігання або суттєвого зменшення рекомендовано ряд сучасних ефективних засобів і технологій підтримання гірничих виробок. Визначено основні фактори впливу на стійкість виробок та побудовано блок-схему їх взаємозв'язків. Виконано класифікацію та визначено рейтинг геологічних, геомеханічних, технологічних і людських факторів впливу, а також їх основних елементів, на стійкість виробок шахт з видобутку урану. Показано, що у вертикальних стовбурах особливу увагу слід концентрувати на ділянках водоприпливів і зон тектонічних порушень та залучати для цього методи неруйнівного апаратурного контролю. В камерах особливу увагу слід приділяти обґрунтуванню їх розмірів з врахуванням фізико-механічних характеристик порід ще на етапі підготовки блоку до його відпрацювання. У підготовчих виробках, особливо з тривалим терміном експлуатації, необхідно: на стадіях пошукових робіт і проектування врахувати дані про тектоніку, тріщинуватість і напружено-деформований стан масиву, а також фізико-механічні властивості порід, параметри виробок і терміни їх експлуатації, тип кріплення та глибину родовища. На стадії проходки – строго дотримуватися технології і паспортів кріплення, а в процесі експлуатації – регулярно моніторити стан виробки і кріплення та виконувати контроль масиву з метою виявлення прихованих заколів і розшарувань. Для зменшення витрат на підтримання виробок рекомендовано використання технологій, що побудовані на синергетичних ефектах в масиві гірських порід.

Ключові слова: уранові родовища, шахти, виробки, стійкість, фактори впливу, класифікація, рейтинг, негативний вплив, запобігання, рекомендації.