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INCREASING THE EFFICIENCY AND ENVIRONMENTAL SAFETY OF COMBINED GEOTECHNOLOGIES FOR LEACHING METALS FROM AND OFF-BALANCE ORES

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Abstract

Goal. Increasing the efficiency and environmental safety of geotechnologies of solid ore extraction with their preliminary grinding with explosives according to traditional technologies and leaching of metals from substandard ores in installations installed in mining workings of the operational block. This will ensure the protection and rational use of the subsoil, increasing the economic efficiency and environmental safety of the mining of poor, substandard and out-of-balance ores in terms of metal content.

Method. The article examines literary sources and patent documentation in the field of geotechnology and technical means of leaching metals from hard ores in energy-disturbed massifs. The technological and geomechanical parameters of operational blocks, laboratory and production experiments, physical modeling of metal extraction from ores of average linear size of a piece of blasted ore mass are substantiated. The theoretical generalization of the process of explosive destruction of rock ores is made, the results of which are laid down in the basis of the technology of breaking for high-quality preparation of ore for leaching in place of its occurrence. The combined method of uranium mining is recommended for use as the most effective. The existing methodology is analyzed and the definition of the parameters of drilling and blasting destruction of ores with a given quality of crushing for preparation for leaching of metal in place of its occurrence is substantiated.

The results. On the basis of research and industrial tests at the Ingul Mine of the State Enterprise "SkhidGZK" of the Michurinsk deposit (Ukraine) of the development of the experimental unit 5–86, the technological operations of the formation of cut-off gaps and compensation spaces are recommended. This will ensure optimal loosening of stored ore under the condition of effective leaching (the loosening coefficient is within 1.15< Kr < 1.2), as well as structural stable parameters of the chambers: height - 20 m; width – 16 m; length - 24 m. It is shown that the most intensive infiltration leaching occurs in the size class of ore pieces - 100 + 0 mm. The specified PBV technology will allow to extract reserves of poor, substandard and off-balance, in terms of mineral content, ores and expand the available raw material base of the mining industry by 1.4-1.6 times, as well as ensure environmental safety of the combined development of strong poorly penetrated ores.

Scientific novelty. It was established that the extraction of metal ξ, %, significantly depends on the average linear size of a piece of mined ore d_{sr} and with high reliability according to the Fisher criterion (R^2 = 0.97) is described by an aesthetic dependence of the type $\xi = 11{,}817\, d_{\text{cp}}^{-0{,}4501}$. A distinctive feature of the proposed method of determining rock destruction parameters at a given quality of grinding of strong ores for leaching is finding the necessary explosion energy, taking into account the maximum energy consumption for crushing the rock. It has also been established that the ratio of the average linear size of a piece of crushed ore mass to the diameter of the borehole (d_s'), required by the condition of maximum leaching of metal, is achieved by matching the level of energy of the explosion, which is transformed into a destroyed massif, with the kinetic energy of the pieces of rock that fly apart, is a logarithmic function of the specific consumption of explosives (q_{EV}) for primary crushing according to the refined formula: $d_s' = -0{,}553 \ln q_{EV} + 2{,}1145$.

Practical significance. It is also recommended to organize hydrogeological monitoring of groundwater sampled through observation wells drilled in the bottom of the production block and to contacts with the ore body, as well as zones of fracture and hydrogeological rupture of rocks. On the basis of the received positive results of the research and implementation of technologies of PBV of metals from rock ores during the development of block 5-

86, in accordance with the issued recommendations, scientific support was carried out during the development of blocks 5-84-86 and 5-88-90, as well as industrial and experimental block 1-75-79.

Keywords: geotechnologies, mining, metal leaching, efficiency, environmental safety.

1.Introduction

Statement of the problem. One of the problems of the mining industry is the high cost of mining and ore processing. On the other hand, the ores that are mined belong to the poor class in terms of the content of the useful component in it. It is possible to increase the efficiency and environmental safety of metal extraction due to the introduction of combined geotechnology, which includes a traditional chamber development system with a solidifying liner, with underground block leaching (BLL) from rock ores [1], [2]. Therefore, the substantiation of combined geotechnology and technical means for PBV of metals from rock ores, which ensure an increase in the economic efficiency of their extraction and environmental safety, is an urgent scientific, practical and social task that requires an urgent solution [3], [4]. Below are the new scientific and practical results of the creation and implementation of innovative technologies of underground block leaching (UBL) of uranium from rock ores, taking into account the permissible seismic fluctuations of the buildings of the residential development of the village of Velyka Balka, Kropyvnytskyi (Ukraine), obtained in the course of scientific research works (scientific head of topics – V. I. Lyashenko): "Seismic monitoring of the action of blasting within the boundaries of the mining diversion of the mines of the SE "ShidGZK" (GR No. 0109U002127) and "Research and development of the seismic-safe technology of working out the reserves of the Western zone of the Central deposit" (GR No. 0109U002125). This work is a continuation of research, the main scientific and practical results of which are most fully presented in the works with the participation of the authors [5], [6].

Objective: Traditional mining technologies together with PBV. There are various technological schemes of PBV, of which the leaching of metals from permeable ores in natural deposits through wells drilled from the day surface is widely used. It is also possible to apply technological schemes of leaching metals at the deposit site and with preliminary crushing of strong ores in chambers with explosives (BP) and commercial leaching of ore-bearing materials on the day surface.

Goal: Increasing the efficiency and environmental safety of geotechnologies of solid ore extraction with their preliminary grinding with explosives according to traditional technologies and leaching of metals from substandard ores in installations installed in mining workings of the operational block. This will ensure the protection and rational use of the subsoil, increasing the economic efficiency and environmental safety of the mining of poor, substandard and out-of-balance ores in terms of metal content.

Methodology: The article examines literary sources and patent documentation in the field of geotechnology and technical means of leaching metals from hard ores in energy-disturbed massifs. The technological and geomechanical parameters of operational blocks, laboratory and production experiments, physical modeling of metal extraction from ores of average linear size of a piece of blasted ore mass are substantiated. The theoretical generalization of the process of explosive destruction of rock ores is made, the results of which are laid down in the basis of the technology of breaking for high-quality preparation of ore for leaching in place of its occurrence. The combined method of uranium mining is recommended for use as the most effective. The existing methodology is analyzed and the definition of the parameters of drilling and blasting destruction of ores with a given quality of crushing for preparation for leaching of metal in place of its occurrence is substantiated.

Tasks: To achieve the set goal, the following tasks were solved:

to establish the intensity of infiltration leaching of metal from ores depending on the size class of ore pieces;

to prove the efficiency of metal extraction by leaching it from stored ores in the chamber due to blast ore preparation; to propose technologies and provide scientific support for the preparation and development of PBV research and industrial-experimental blocks.

2. Analysis of recent research and publications

In the process of research, a complex method was applied, which includes an analytical approach using the basics of system analysis and mathematical statistics, performing technological experiments using economic and mathematical modeling, technical and economic calculations and research and industrial implementation [7], [8]. The method of comprehensive generalization, assessment of practical experience and scientific achievements in the field of geotechnology, theory and practice of explosive destruction of solid environments is also used. The methods of the mechanics of continuous media and research techniques for evaluating wave processes have been implemented according to standard methods developed by leading specialists of developed mining countries with the participation of the authors [9], [10].

Mountain technology. At the deposits of SE "ShydGZK" (Ukraine), various options of chamber systems are used, with the filling of the produced space with a hardening mixture of different composition and strength. They have general and distinctive features and are used for excavation of deposits with different geomorphological characteristics and ore-bearing capacity. Since in the case of chamber systems of sub-floor shafts (orts), after ore mining, the cleaning space is filled with a hardening mixture and the operational blocks are worked along the extension in 2 stages, and the cross extension in 3-4 stages, it is necessary to leave the ore inter-chamber and inter-surface wholes. In fact, chamber systems with solidification of the cleaning space are systems of continuous mining of ore deposits along the rise and strike (Fig. 1). Depending on the strength of the ore body (M), steeply falling ore bodies (angle of inclination > 50°) are mined by a system of underground shafts (M = 3 – 20 m) or a system of underground pits (M > 20 m) with a lining.

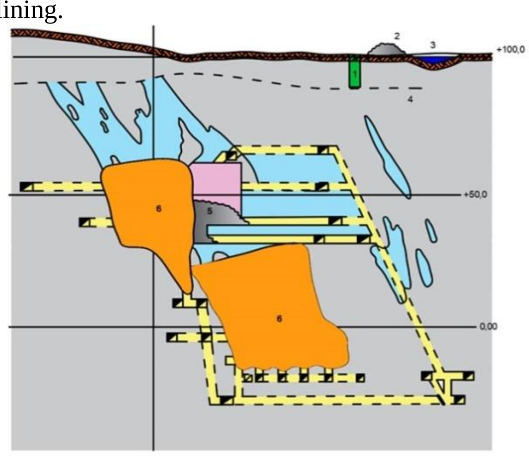


Fig.1. Chamber mining system with end ore release: 1 – anti-filtration curtain; 2 – dam; 3 – Ingul River; 4 – lower boundary of weathering crust; 5 – broken ore; 6 – chambers worked out and quenched with hardening backfill

Ore and host rocks are stable, with a fortress coefficient on the scale of prof. M.M. Protodiakonova at least 12. Block parameters: height 60 - 120 m; - length 20 - 60 m; - the width is 15 - 20 m (when placing the cameras in the cross of the strike) or equal to the capacity of the ore body (when placing the cameras along the strike); floor height up to 15 m (in exceptional cases up to 17 - 18 m); bottom height 8 - 11 m (maximum 13 m with secondary crushing horizon); the distance between the outlet ducts is 8-10 m. In the course of more than 50 years of development of the deposit, the chamber system of development with ore removal from the underground shafts (orts) and paving with hardening mixtures has been well developed, has high labor productivity, a relatively low cost of production and the most important thing is high intensity, which is very important when bringing into exploitation the sub-river deposits of the Michurinskoye deposit.

For operational control and forecasting of the stress-strain state of the mining massif (SDS), soundometric devices were used, in particular, portable as the simplest means and methods of observation (developed by the research and production complex of automation and mechanics (NVK "A and M"), manufactured together with repair - mechanical plant (RMZ) of SE "ShidGZK", Ukraine) and others. Development systems are performed in two versions, which differ in the bottom of the block and the equipment used for ore extraction - through the pipes of the PVG-1.2/3.1 or PVG-1.3/7.0 vibratory feeder to the VG-4M trolleys. It was also used end-to-end production or through production products by MPDN-1 (Ukraine) or ULE-2 (Germany) cargo-delivery machines with manual and remote control. The clean extraction of camera stocks begins with the formation of cutting slits. The removal of chamber reserves is alternated with the release of ore into vehicles to the rollback horizon, the slaughter line is stepped or close to vertical. The reflected ores are released from the chambers sequentially through one, two, three or more pipes depending on the length. Chambers located in powerful ore bodies with a significant extension (200 - 300 m) work out the reserves in 2 - 3 or more lines, and extraction of the reserves of chambers located along the extension is carried out in two lines. Mining preparatory work consists in carrying out ore and field stretches (orts) on rolling and ventilation horizons, ventilation collector, block vertical workings and ore descent. Moreover, under the condition of application of centralized (group) training, block vertical workings and ore descents pass to a group of operational blocks (from 3 to 5 blocks). There are options for preparation with the passage of ramps for the delivery of machines, equipment, materials, supply of fresh air to the pit, etc. Rigging works consist in carrying out undercut and underfloor trenches (orths), cut-off butts and risers, outlet ducts, failures.

Mining works are carried out at a depth of 40-50 to 350 m. Chambers are worked in sub-floors with a height of 10-15 m. The ore is beaten with well charges with a diameter of 57 and 65 mm. Wells are drilled with NT-2 and PK-75 and Norit machines. Parallel downholes with a diameter of 85 and 105 mm for the formation of cut-off slots are drilled with NKR-100 M machines (Ukraine). Self-propelled drilling equipment of domestic production is also used for tunneling and cleaning works: drilling rig BU-85S;

a column for drilling holes with a manual perforator LKR-MN; UBSH-201 drilling shaft installation; UBSH-203 drilling shaft installation;

PT-2ESH-M electro-hydraulic truck, as well as foreign companies "Atlas Copco" (Boomer 281, Boomer S1D drilling rigs; Wagner ST-3.5 truck and delivery truck; "Tamrock", etc. [11].

After the release of the rock mass from the chamber, preparations are made for laying with the help of insulation of the cleaning space with jumpers on all floors and in the bottom. It takes a certain amount of time to pave the cleaning space and harden the artificial array, and the normative strength of the hardening pave varies depending on the sequence of working out the chamber. Therefore, the stocks of cameras of the second and subsequent stages are used up no earlier than in 6-8 months. This is the time during which cleaning work is allowed in the cell adjacent to the blocked cell.

The analysis shows that an increase in the specific flow of BP above the limit q = 3.0 kg/m^3 does not lead to a significant improvement in the quality of crushing. The consequence of the increase in the value of q to 5.0 kg/m^3 is the strengthening of ore crushing and the increase in the yield of very small fractions.

Blasting with charges through boreholes with a diameter of 85 mm and 100 mm is characterized by almost the same indicators of granulometric composition as blasting with charges with a diameter of 67 mm. However, the specific consumption of BP when using wells of a larger diameter is much lower. Based on this, for the Michurinsky deposit, with the further development of the technology of PBV from stockpiled ores, it may be recommended to switch to the drilling of the ore massif with drill holes with a diameter of 85 mm. The height of the ore store is recommended to be 50 m [12], [13].

Geochemical technologies. In the implementation of mining technologies in combination with PBV, leaching schemes from permeable ores in natural deposits through wells drilled from the surface are widely used. It is also possible to use schemes with preliminary crushing of rock ores by detonation of BP. The authors propose the introduction of a new, cheaper technology for the extraction and processing of poor and out-of-balance ores in terms of the content of a useful component, consisting of a traditional chamber system with a hardening embedding mixture of different composition and strength, as well as PBV [14], [15].

The mentioned metal leaching technologies provide for the supply of a leaching solution (in this case, it is a low-concentration solution of sulfuric acid on the ore-bearing material, as well as the preparation of the receiving horizon in the form of a bottom silted with a clay solution at an angle of up to 5-6° to the horizontal. The time of metal leaching is from 6 to 8 months. After that, the productive solution is collected in containers and sent for further processing to the hydrometallurgical plant (HMZ), and the leached material is left in spent chambers as an investment mixture with a strength of up to 1.0 MPa and is washed with water through an operating irrigation system to reduce its ingress into the geological harmful substances [16], [17].

The effectiveness of the application of the specified technology is achieved with the following basic mining-geological and mining technical characteristics of ore deposits: stable and medium-stable steep-falling ore bodies located in rocky acid-water-resistant host rocks; by quality (useful component content) ores - balance, poor and off-balance; fracture zones in the surrounding block space are weakly developed, the carbonate content is slightly more than 2–4%; ore deposits have significant out-of-balance halos in the absence of clay inclusions. The most common technological operations of PBV of metal from ores are given in Table 1 [18].

Table 1.

Technological operations of underground block leaching of metal from ores

Mining enterprise (field, mine)	**The beginning of development of PBV technology**	**Technological operations**			
		Ore preparation	**Supply of leaching solutions**	**Delivery of productive solutions**	**Transportation of resin to the GMZ**
Lermontov mining and chemical ore management (Bykohirske) North Caucasus	1963	Without destruction of the ore massif	From a sorption column placed on the surface	To the sorption column placed on the surface	In tanks
PJSC "PPDGO" (Strlitsivsk Ore Field), Russia	1983	Ore chipping by blasting	The same thing	The same thing	The same thing
JSC "CGHK" (Zoryane, East, Semizbay), Northern Kazakhstan	1968	Ore chipping by blasting	– ″ –	– ″ –	– ″ –
SE "SkhidGZK" (Michurynske, "Ingulska" mine), Ukraine	1999	The same thing	From the sorption column placed in the mine workings of the irrigation horizon	From the catchment sump to the sorption column placed in the mine workings of the irrigation horizon	In trolleys to the earth's surface and then in tanks to the HMZ

3.Theory of Question

Predictive assessment of the granulometric composition in the massif of rocks. In order to determine the fracturing ***Tr*** (the number of cracks per 1 meter of core of the investigated rock massif of boreholes or boreholes) of new sections of exploited deposits, where the network of mining workings is very rare or absent at all, it is possible to use, as a first approximation, the dependence derived on the basis of the study of the core output of exploratory and exploitation-reconnaissance wells, as well as the cracking of the sides and roofs of the workings in the sections:

$T_r = b_1 - b_2 M$, (1)

where $b_1$and b_2 are linear coefficients (for migmatites $b_1 = 12{,}3$, $b_2 = 0{,}06$; for granites $b_1 = 17{,}8$, $b_2 = 0{,}12$; for albitites $b_1 = 12{,}6$, $b_2 = 0{,}057$; M-output of the core, %.

The correlation equation has the following form: $C = a_1 M - a_2$, (2)

where $a_1$and a_2 are linear coefficients, the values of which for different rocks and deposits as a whole are given in Table 2.

Table 2.

Values of linear coefficients

Coefficients	a_1	a_2
Granite	0,00580	0,0507
Gneisses	0,00603	0,0676
Migmatites	0,00540	0,0149
Albitites	0,00619	0,0680
Average coefficient for the field	0,00681	0,1259

*Crushing of chamber reserves of ore with a given quality.*It can be seen from the given dependence that the energy used for the explosive preparation of the mining massif depends on its physical and mechanical characteristics and the geological properties of the ore. Knowing the specific consumption of explosives, the authors determined the charge mass per borehole and the geometric parameters of the borehole arrangement in the blasted production block. The authors also established the predicted blockiness B and the specific fracturing of rock massifs depending on the block diagonal ***D*** using the example of uranium deposits of the Ingul mine. In particular, it also depends on the number of pieces (blocks) ***Nk*** (at ***D***>70 cm) and the specific fracturing of the massif ***Tr.***

It consists not only in determining the quantitative parameters of blasting, which can be established according to laws with a sufficient degree of reliability, but also in determining the peculiarities of the preparation of the ore mass and accounting in the management of technological parameters. Reducing the average diameter of ore pieces, crushing the leachable media in order to increase the previously existing surfaces, this allows to reduce the average linear size of the piece and increase the newly formed area of the destroyed rock massif, is the preparation of the ore mass during ore striking in the clamp

When preparing the mining ore mass, it is essential is influenced by the amount of compensation and the technique of blasting. The concept of the compensation coefficient of the compensating volume was introduced from the following premises:

in its natural, undisturbed state, the mountain massif occupies a unit of volume (m^3);

in the destroyed state and depending on the lumpiness, the volume unit is characterized by the loosening factor, which can vary from 1.5 to 3.0;

in mining, the loosening coefficient of a unit volume of a rock mass varies from 1.5 to 1.8, depending on the lumpiness;

when the loosening factor is less than 1.5, the process of clamping the mining mass occurs.

The lower the blockiness index in absolute terms, the greater the compression of the rock mass placed in the compensating volume. When the loosening coefficient is less than 1.25, there is a process of deep clamping, when the rock mass is compressed and loses mobility, which is characterized by the term "clamping coefficient". It has also been established that the ratio of the average linear size of a piece of crushed ore mass to the diameter of the borehole (***d**ₛ'*), required by the condition of maximum leaching of metal, is achieved by matching the level of energy of the explosion, which is transformed into a destroyed massif, with the kinetic energy of the pieces of rock that fly apart, is a logarithmic function of the specific consumption of explosives (q_{EV}) for primary crushing according to the refined formula: $d_s' = -0{,}553 \ln q_{EV} + 2{,}1145$. (3)

The parameters of the blasting operation for breaking the chamber stocks of the PBB blocks 5-84-86 and 5-88-90 are given in Table 3.

Table 3.

Safe and effective parameters of the chambers for PBV of metals of ore deposits

Parameter names	Calculation formulas
Line of least resistance (LNO), m	$W = K_{mp} \cdot \frac{90}{\sqrt{f}} \cdot \sqrt{\frac{e}{e_{эт} \cdot m}} \cdot d_{скв}$
The coefficient of convergence of wells should be taken in the range of 1.5–2.5, taking into account the influence of mining technical and technological factors	$m = 3{,}0 - K \cdot \frac{h}{B} \cdot d_{скв}$
The distance between the ends of the wells in the fan, m	$a = m \cdot W$
Recalculation of LNO, m	$w_n = \sqrt{\frac{a \cdot W}{m_n}}$
The length of the operational block l to achieve the specified quality of mining mass crushing, m	$\ell = 2(K+m)+в_1$
The width of the compensation space during the explosion in the clamp is determined by the width of the cut-off gap v0 and the	$в_1 = в_0 + 2l_в$

length of the partial release section lv, limited by the expansion coefficient 1.15>***Kr***<1.2, m	
The effective height h of the stored mining mass in the PBV, taking into account the technological and hydrodynamic characteristics of leachable ores, m	$h = \frac{\theta \cdot t}{V \cdot \gamma}$
Note: ***W*** is the line of least resistance, m; ***Ktr*** is a coefficient that takes into account the fissuring of the rock massif (varies from 0.95 to 1.1); f is the strength coefficient of rocks according to the scale of Prof. M.M. Protodiakonova, unit.; e_{em} – volume concentration of energy for the reference BP (accepted ammonite No. 6ZhV), kcal/cm^3 ($e_{em} = A_{em} . r$); ***e*** – the same, for the applied BP, kcal/cm^3 ($e = A_{вв} . r$); $d_{св}$ - diameter of wells, cm; m - coefficient of convergence of charges (varies from 1.0 to 1.3), unit; A_{em} and $A_{вв}$ – complete ideal work of the explosion of the reference and applied BP, respectively, kcal/h; ***p*** – charge density (varies from 0.8 for BP type gram-monite 79/21; granulite AS-4; AS-4B; AS-8; AS-8B to 1.6 – for rock ammonite No. 1, etc.) , g/cm^3; ***h*** – the maximum size of the floor for a specific block, m; ***B*** - width of the block (chamber), m; ***K*** is a coefficient that depends on the ***h / B*** ratio and other mining technical factors: with ***h / B*** = 1.05, ***K*** = 0.13; with ***h / V*** > 1.3, ***K*** = 0,10; m_n – new convergence coefficient, unit; $в_1$ – the size of the compensation space, m; θ irrigation mode, m^3/m^2•time; ***t*** – time of intensive leaching, hours; ***V*** –reagent consumption per 1 ton of ore, m^3; γ – density of leaching ores, t/m^3	

Study of the dependence of metal recovery on the average size of a piece of ore. The technical task, for the solution of which the proposed combined technology is used, is to increase the efficiency of the process of developing ore deposits in combination with PBV by optimizing the parameters of operational units and creating conditions for managing the energy of explosive destruction. This ensures the optimal granulometric composition of the mining mass of the specified crushing quality, as well as the metal leaching coefficient from the ores and the reduction of the consumption of technological solutions during the leaching of useful components. In the active mines of Ukraine, the combined method of metal extraction is recommended for use as the most effective. It has been established that the volume of preparatory mining works for the combined method of extraction directly depends on the completeness of the use of previously completed (existing) mining operations and the adopted PBV scheme.

A distinctive feature of the methodology for determining rock ore destruction parameters with a given crushing quality for leaching is finding the necessary explosion energy taking into account the ultimate energy intensity of rock crushing. Knowing the specific flow of BP, it is possible to determine the mass of the charge per well and the geometric parameters of the location of the wells in the exploding block. From the analysis of the expression, it follows the expediency of reducing the average diameter of pieces of reflected ore, as well as crushing the components of the leaching media in order to increase the contact surfaces. The regularity described by the specified expression is important in controlling the following parameters of the leaching process. One of such methods, which allows to reduce the average linear size of the piece and increase the newly formed area of the collapsing rock massif, is the preparation of the ore mass for leaching using the kinetic energy of the flying pieces of rock, with the subsequent chipping of the ores in the clamp [19], [20].

Drilling wells and charging explosives, its short-delayed detonation in a confined environment are carried out. They carry out the passage of the irrigation horizon and the bottom for collecting productive solutions, partial release of the reflected ore into the cut-off slot (up to 30%). In the process of development of rock ore massifs that are poorly penetrated, preparatory and cut mine workings, cutting slots and their expansion are carried out. The existing methodology was analyzed and the determination of the parameters of the destruction of uranium ores with a given quality of crushing for preparation for leaching of uranium at the place of its occurrence was substantiated.

One of the methods that allows you to reduce the average linear size of the piece and increase the newly created area of the collapsing rock mass is the preparation of the ore mass for leaching using the kinetic energy of the flying pieces and crushing the ore in a clamp. Taking into account that the values of the experimental and calculated values of the specific flow of BP practically coincide, we will get the following picture of the location of the well charges along the circular fan using the example of the location of the deposit at an angle of 50 °.

The proposed technology is aimed at improving the efficiency of the development of PBV ore deposits, by optimizing the parameters of operational units and creating conditions for controlling the energy of explosive destruction, ensures the optimal granulometric composition of the rock mass of the specified crushing quality, as well as the coefficient of leaching of metal from ores and reducing the consumption of technological solutions during leaching [21]. Based on the results of multi-year studies of a complex of scientific and research works during the underground development of deposits of a complex structure in energy-disturbed massifs, which are being developed by SE "ShidGZK", Ukraine, the authors offer calculation formulas for substantiating the parameters of drilling and blasting operations and the safe parameters of chambers (length, width and height). taking into account the effectiveness of the PBV of metals, as well as seismic - taking into account the correction of the known formulas of Prof. M.A. Sadovsky (Table 3) [22].

Underground leaching of metal from ores. Until the beginning of the 70s of the last century, the balance reserves of the Bykohirsky uranium deposit (North

Caucasus, RSO Alania) were exhausted by traditional systems with laying and storing of ore with processing at a hydrometallurgical plant. In the future, the above-mentioned deposit was developed using underground leaching methods. Since 1963, the enterprise began to master the method of underground and heap leaching when working out poor ores classified as out-of-balance for the traditional method (Fig. 2).

At the same time, the problem of disposal of off-balance ores in dumps, stored during clean mining, was solved by processing them by leaching. Rationalization of leaching methods made it possible to: increase the safety of work; - reduce the amount of cutting work by 3 times; to increase the efficiency of mining and preparatory works by 2.5 times; increase active ore reserves by 20-30% due to the elimination of the need to leave block wholes; reduce metal loss. Without prior destruction by the filtration flow of the reagent, areas of the Bykohirsky deposit were leached in the zone of pressure fracture waters, the level of which is 2-4 m below the deepest horizon (435 m). Metal from ores with natural permeability was leached by filtration flows of reagent solutions with sectional supply and reception of productive solutions in wells. .Leaching was carried out by a filtration flow of solution with a main pressure of 0.6 MPa into the pumping fans of the well and by pumping productive solutions from the drainage fans with the help of electrovacuum units.

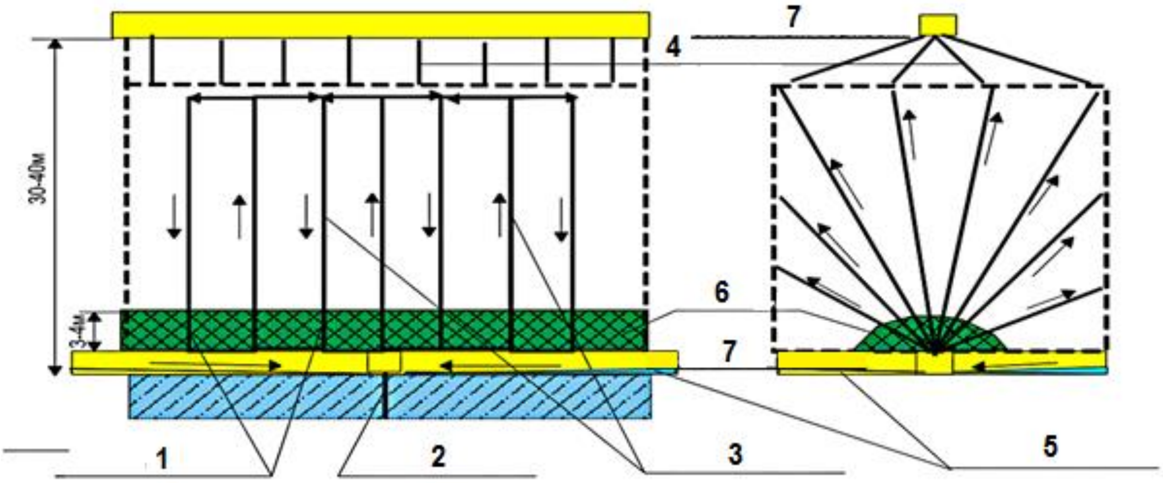


Fig.2. Preparation of ore bodies for PBV from permeable ores in natural occurrence through wells: 1, 2, 3, 4 – drainage, bypass, supply and irrigation wells, respectively; 5 – waterproofing; 6–tamponage; 7-rollback horizon

Rationalization of parameters of leaching technologies ensured extraction of 15% of metal from off-balance ores. Flows of working and productive solutions were regulated using a piston-type injection device. The intensification of PV processes during the leaching of ores without destruction at the Lermontov Mining and Chemical Ore Management (North Caucasus, RSO Alania) deserves attention. Compressed air was used as an intensifier, which was supplied to injection wells in the final stage of leaching (Table 4).

Table 4.

Indicators of development of the Bykohirsky deposit by the PV method

Name of indicators	**Value**
Minable reserves, %	500
Release of metal into finished products, %	225
Through metal removal, %	82
Annual productivity: by ore, %	650 160
by metal, %	59
Extraction of metal from ores at PV, %	267
Enrollment, people.	311 220
Metal production per 1 worker, kg/m^3	1,1
The full cost of 1 kg of metal, monetary units. , %	34 80

Compressed air serves not only as a good oxidizer, but it promotes the penetration of the reagent through pores and cracks and thereby improves the effective diffusion coefficient. The average metal content in productive solutions at the final stage of leaching increases by 2.0–2.5 times.

*Combined geotechnology of ore extraction.*Mining regions are characterized by the development of mineral deposits, which may be of interest in resuming mining operations. Many exploited deposits can be redeveloped because they consist of separated from the massif and crushed rock mass available for leaching. The condition for the use of such technologies is to ensure the size of the reacting particles and the related filtration capacity of ores, which is provided within the framework of combining geotechnologies, depending on the preparation schemes and the ore leaching mechanism in the PBV block (Fig. 3 and Fig. 4).

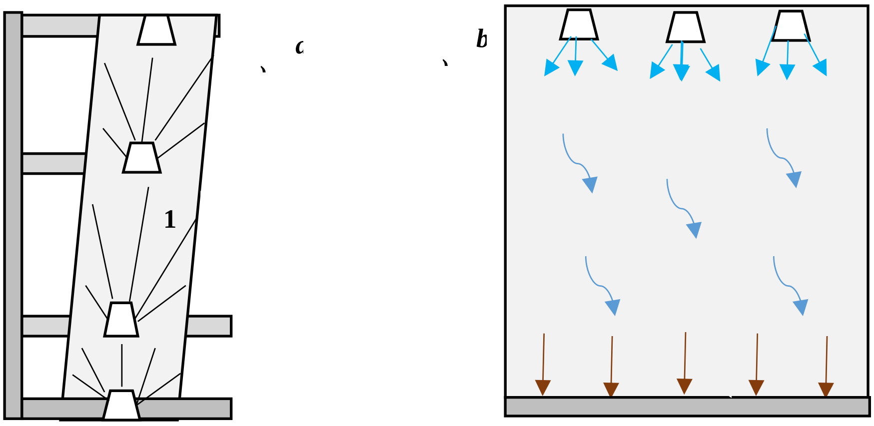


Fig. 3. Scheme of preparation and mechanism of ore leaching in the PBV block: A – block preparation and ore crushing; B – movement of reagents; 1-ore; 2- preparatory works; 3 – explosive wells; 4 - supply of leaching solutions; 5 - collection of production solutions

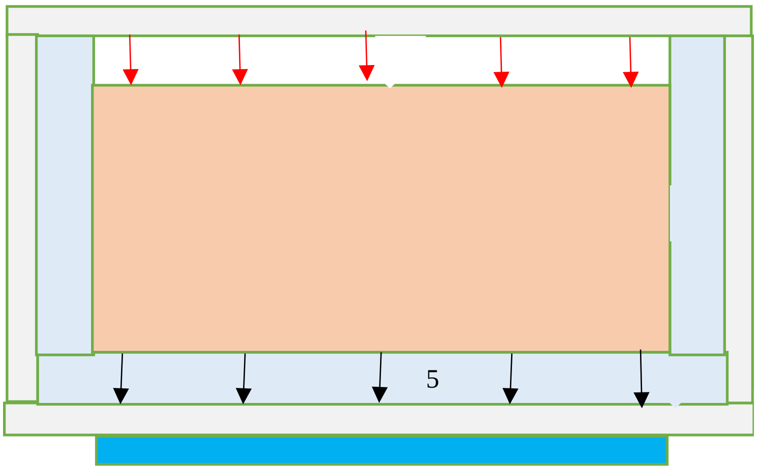


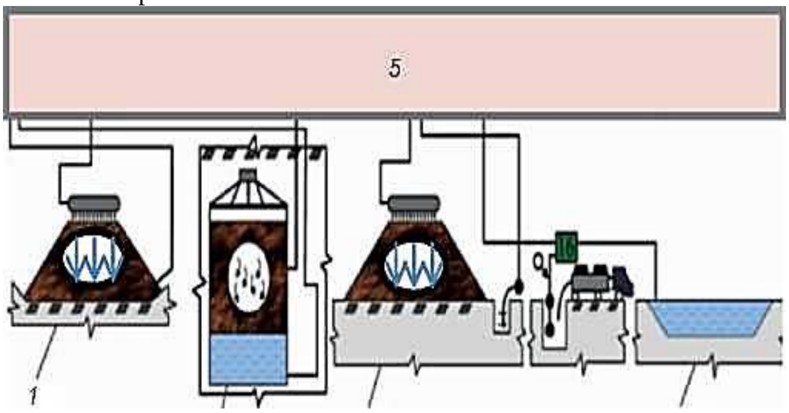
Fig.4. Schematic of ore leaching in the shop of the PBV block: 1 – preparatory workings; 2- targets; 3-stored ore; 4 – working reagent solution; 5 - production solution of the reagent; 6 - products from the collection of productive solutions

Highlighting the previously unsolved part of the general problem. Metal leaching systems in blocks (PBV) are used in deposits characterized by sufficient active porosity and filtration capacity. The shortcoming of the specified PBV systems is the lack of justified parameters of drilling and blasting operations, which ensure the specified quality of crushing and technological conditions aimed at fuller use of the energy of explosive destruction, in addition to slow separation and detonation in a confined environment. In addition, the stable parameters of operational units of PBV have not been determined, which, without taking into account the management of the energy of explosive destruction, can lead to the collapse of their structural elements. As a result, one of the most problematic areas is the difficulty of achieving the specified quality of crushing, as well as the necessary height of ore storage in the chamber for further leaching of metals and the coefficient of loosening, taking into account the management of the energy of explosive destruction of rock ores. Monitoring of contamination of the hydrogeological environment is carried out by examining water samples taken in the zone of influence of leaching facilities.

4.Presentation of the main material

Based on the analysis of the applied technologies of underground development of rock deposits, it is proposed to introduce a new, cheaper technology of extraction and processing of poor ores - a combined one, consisting of a traditional technology of development in combination with PBV. The mining enterprise goes through several stages. The first stage is characterized by anticipatory excavation of rich areas of the deposit with compensation of technological losses by increasing the amount of extraction of rich ores. The second is characterized by a decrease in reserves of rich ores, and a decrease in the content of metals in the ore is compensated by an increase in the production of smaller raw materials. The third is the extraction of metals from substandard ores and processing waste.

When combining technologies, rich ores are brought to the surface and processed at the plant, and poor ores are leached in underground blocks and stacks (commercial leaching) with the production of metals, building materials, desalinated water, gases, acids and low-grade alkalis. Such technologies are effective when 40% of the rich ore is exposed to the surface and 60% of the ore is leached underground. With the same productivity of the enterprise from the mining mass, the productivity from the metal increases twice (Fig. 5).



2 3 4

Fig.5. Combined leaching of metals: 1 – KV stack; 2 – PV block; 3 – dump; 4 – pond; 5 – solution processing workshop

The authors indicate that this method allows to significantly reduce the operations used in the traditional mining system (except such as: creation of compensation space, release and delivery of up to 30% of stored ore from the PBV chamber, etc.) [23], [24]. The PBV method is used for ores with a metal content of less than 0.15%. The ore stored in the chamber is irrigated with a solution of sulfuric acid during the year. In the lower part of the chamber there is a drainage pipe for collecting productive solutions, from which they are pumped through a pipeline to a surface technological installation for primary processing. The resulting semi-finished uranium is transported by car to the GMZ. Uranium losses by PV technologies do not exceed 30–35%.

Parameters of drilling and blasting operations. The authors have made a theoretical generalization of the process of explosive destruction of rocky uranium ores, the results of which are laid in the basis of the technology of chipping, which will be able to ensure high-quality preparation of uranium ore for leaching at the place of its occurrence. The combined method of uranium extraction is recommended for use at the operating mines of Ukraine as the most effective. It was established that the volume of preparatory mining works, with the combined method of extraction, directly depends on the completeness of the use of previously completed mining works and the adopted PBV scheme. Studies have shown that, despite the differences in the considered variants of schemes for the preparation of blocks for leaching, their common feature is the high demands placed on the quality of drilling and blasting work, as the main technological process that ensures ore preparation for further effective extraction of uranium from stored ores.

5. Results

Scientific result. In conditions of Michurinskoye deposit of State Enterprise "VostGOK" (Ukraine) large-scale studies of dependence of metal extraction from crushed and fractionated ore mass were conducted, which allowed to establish quantitative parameters of leaching process. It was established that metal extraction ***ξ*, %**, essentially depends on average linear size of blasted ore piece d_{cp} and with high degree of reliability (R^2 = 0, 97) is described by expression of type $\xi = 11,817\, d_{\text{cp}}^{-0,4501}$. A distinctive feature of methodology of determination of parameters of destruction of rocky ores, with given quality of crushing for leaching, is finding of required energy of explosion taking into account maximum energy intensity of rock crushing. Knowing specific consumption of explosives, it is possible to determine mass of charge per one borehole and geometric parameters of boreholes arrangement in blasted block. The analysis of the expression shows the expediency of reducing the average diameter of broken ore pieces, as well as crushing the components of the leached media in order to increase the contact surfaces. The described regularity is of great importance in managing subsequent parameters of the leaching process. One of such methods, allowing to reduce the average linear size of a piece and increase the newly formed area of the destroyed rock mass, is the preparation of the ore mass for leaching using the kinetic energy of flying pieces of rock with subsequent breaking of the ores in the clamp.

Practical result. The width of the PBV operational block, equal to the equivalent span with the proposed length and effective height of the leachable ores, ensures the stability of the exposure of the horizon without collapses and collapses during the leaching period without violating the technological and hydrodynamic characteristics of the stored in the block. The optimal parameters of the process of development of rocky mountain massifs of PBV are ensured by the loosening coefficient, which is determined from the conditions of control of the energy of explosive densification. The loosening coefficient creates the conditions for obtaining the granulometric composition of the specified crushing quality without the formation of channels for the leakage of productive solutions in the areas of overcompaction of the reflected mining mass, since the penetration of productive solutions in such conditions is practically excluded. This operation, associated with obtaining the necessary coefficient of loosening, allows to increase the extraction of useful components from ores to economically feasible limits. The BVR parameters for striking the chamber reserves of PBV blocks 5-84-86 and 5-88-90 are calculated and entered in accordance with the Table 5.

Table 5.

BVR parameters of blocks for reflecting chamber stocks

It's time to blow up	**Fans of well charges along the horizons of (sub-floors)**	**BVR parameters**				
		d_{skv}, mm	***W*, m**	**distance between wells (*a*), m**	**convergence factor of wells, (*m*)**	**specific consumption BP (q), kg/t (kg/m^3)**
Bloc 5-84-86						
1st explosion	–260 m (1’-5’, 1-8)	85	1,8	1,9	1,06	1,16 (3,07)
	–240 m (1б-6б)	85	1,8	1,9	1,06	1,08 (2,88)
	–240 m (1’-5’, 6)	67	1,2	1,2	1,0	
2 st explosion	–225 m (1’-3’, 1-7)	105	2,0	2,2	1,10	0,945 (2,5)
3 st explosion	–210 m (1A’-3A’, 1-10, 1A-10A)	105	2,0	2,2	1,10	1,28 (3,39)
Bloc 5-88-90						
4 st explosion	–263 m (1’-3’, 1-7)	85	1,8	1,9	1,06	1,27 (3,27)
	–225 m (1’-3’, 1-7)	105	2,0	2,2	1,1	1,02 (2,70)
	–210 m (1’-3’, 1-7)	105	2,0	2,2	1,1	1,00 (2,65)

The number of BP for one deceleration in the case of counter-blasting by fan well charges when calculating the displacement rates of rock massifs (underground objects) and the speed of soil displacement (surface objects) is not summed up, since the direction of the fronts of seismic oscillations after the simultaneous explosion of the layers of the rock massif mutually opposite (Table 6).

Table 6.

The maximum number of BP in one deceleration in blocks 5-84-86, 5-88-90

Bloc	**Horizon, m**	**Fan number**	**A series of decelerations, ms**	**The maximum amount of BP for one deceleration, kg.**
5-84-86	225-210	8-8A	150	2777
5-88-90	263-240	2	50	1969

The proposed technology for the development of poorly permeable rock massifs of PBV is carried out as follows. The ore body is divided into operational blocks, preparatory mining and cutting operations are carried out. Make a cut-off slot and a flat bottom of the camera. Drilling is carried out with parallel fans of wells with a diameter of 50-85 mm from underground workings. Partial (up to 30%) gravity release of the stored ore is carried out to the rolling horizon through the ore release workings located in the lower part of the production block, and further transported by trucks. After repelling the ore, an irrigation system is installed in the upper part of the chamber, consisting of a set of pipes and nozzles for supplying leaching solutions, and in the lower one, productions (sumps) are equipped for collecting productive solutions. Supply of leaching solutions to the chamber is carried out until the condition of its concentration in the productive solution is reached (up to approximately 4 months).

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The collection of productive solutions and their delivery for hydrometallurgical processing is carried out after reaching the condition concentration of the metal in the productive solution. After the process of leaching stored ores in the chamber, the leached material is supplied with technical water from the wells for the inflow of leaching solutions (irrigation system). The leached material is left in the cells as an embedding mixture. Its uniaxial compressive strength reaches 1.0 MPa. To increase its strength, it is sealed with a hardening solution. In contrast to known technologies and technical means for leaching metals from rock ores, leaching and productive solutions are pumped from the lower to the horizon lying above, without releasing them to the earth's surface. Products are delivered to the earth's surface in carts in the form of resin for further processing at the landfill. In essence, the mine will equip an underground area for leaching metals from rock ores in PBV blocks and installations located in underground workings. This method makes it possible to significantly reduce the operations used in the traditional mining system (except for those such as the creation of compensation space, the release and delivery of up to 30% of the stored ore from the PBV chamber, etc.).

Experience of development of operational block 5-86 PBB of Michurinskoye field. Deposit 5 is located in the same place as deposit 4, but is separated from it by one of the branches of the western gneiss pack. The basis for the formation of deposit No. 5 was the areas of the Southern granite massif, which underwent intensive crushing. Deposit 5 is controlled by the SW3 fault zone, investigated at 25 intersections, including 3 transverse ones. The strike of the deposit varies from 310-330° in the central part to 295-300° in the north, near the bend. The angles of incidence in the southern and, especially, in the near-surface parts become more gentle. In the XI+50 profile, the deposit is exposed to loose deposits. Its greatest length along the extension is noted at the -93 m horizon. The maximum thickness of the deposit is noted at the -153 m horizon, the average thickness at other horizons does not exceed 10 m, and only above the +27 m horizon it increases again to 15 m.

During the experiment, the irrigation density varied from 9 to 16 $l/m^2 \cdot h$, which provided an infiltration mode of irrigation. During the preparation for PBV, the authors recommended the possibility of maximum use of previously passed mining workings. On Mt. -210 m, there is a sorption column with a container for receiving sorbent, a main pipeline with a sprinkler system for supplying leaching solutions to the stored ore in the PBV chamber [25], [26]. On Mt. -255 m equipped pumping stations with sumps for neutralization solutions, preparation, acidification and capture of productive solutions. From the mountains - 280 m of drilled wells to monitor changes in the hydrogeological environment and carry out appropriate monitoring. In this mode, working solutions are supplied from the irrigation horizon (height 210 m) to the surface of the ore that is cut in the block through a system of perforated polyethylene pipes with a diameter of 16 mm. Pipes are inserted into 48 wells drilled from the mountains. 210 m down into the block chamber. The total length of these wells is 309.2 m, the network of irrigation points is 2 x 2 m. Irrigation is carried out periodically for 30 minutes. with breaks of 2-3 hours sparingly soluble tetravalent form into easily soluble hexavalent form. Geochemical technology at the experimental site of the PBV includes the following operations [27]: irrigation and acidification of the reflected ore with sulfuric acid solutions; sorption of metal from productive solutions onto resin (regenerated AMP brand anionite); intensification of leaching processes with shaking explosions; pumping through the mine's main drain of excess solutions after sorption to the mine water treatment plant (UOSHV); neutralization and washing of spent ore mass with lime solution and mine water.

The leaching process is provided by technological equipment, which includes: a surface unit; technical complex of receiving and issuing acid and resin; underground node; technological complex of leaching and sorption. Sulfuric acid from a railway tank, which is used as a waste container, is periodically pumped into a transport wagon - a tank - by a pump through an intermediate tank and a draining device. A tank wagon with acid is lowered with its trunk on the mountain. 210 m. According to the technological regulations, the acid is dosed at the mountain. 240 m in a sump of productive solutions - for preparing a leaching solution. The circulating solution is pumped from mountains. 240 m into the irrigation system of the block. Irrigation is carried out through wells drilled in the trunk of the block chamber.

The solution seeps through the entire massif of crushed ore and drains through a ditch into a sump of productive solutions. After saturation of the productive solutions with the leached metal, the solutions are pumped to the sorption column, where the metal settles in the resin. Control capture of "slippage" of the resin is carried out on the rumble and in the form of filtrate is fed to the mother tank for strengthening with acid, from where it is pumped again into the irrigation system and then - into the chamber of the block. Occasionally, when there is an excess of productive solutions in the sump due to water inflow, part of the solutions (volume up to 10 m^3) after sorption is neutralized with lime in the neutralization sump and then pumped into the general drainage ditch. From it, the solution enters for dilution in the sedimentation tank of the mine's main drainage, with subsequent pumping at UOSHV installations [28]. Calculation of the parameters of drilling and blasting operations and well charges was carried out by horizons, workings, fans and operational blocks in accordance with the Forms given in the Table 7.

Table 7.

Form of calculation of well charges of BP by explosion objects for the operational block of PBV

Fan number, number of wells	Well number	The length of the well, (L), m	The amount of undercharge, m	The length of the charged part of the drill bit (L_3), m	Well charge mass, kg		The number of tonator electrodes, detonating cord, units.	Release series number, ms	Diameter of the well, mm
					granular	patronized			
Horizon 240 m. Ort drilling									
Together	–	227,5	63	164,5	1064	13	44	2 (75)	85

Periodically, the saturated resin from the sorption column is unloaded into a special tank wagon and raised to the surface, where with the help of "transport" water from the pump, a 6.4 m^3 tank truck is sent by gravity and transported for regeneration to the landfill. The regenerated resin is loaded into the wagon from the tank truck by gravity - with the help of circulating water, which during loading drains from the wagon or tank truck through a cartridge filter. At the rolling horizon, the resin is fed from a tank car into the sorption column by airlift. After the completion of leaching, washing and neutralization of the block, insulating and ventilation bridges are constructed in all adjacent workings of the horizons of 280, 240 and 210 m to prevent emanation of radon and other harmful substances. Research has established that after leaching there was a change in the granulometric composition of the ores. The leached ore, after delivery from the block to the wagons and transportation to the surface, was carefully classified on the rumble through variable sieves at the ore beneficiation plant (ROF), collected and weighed fractionally.

During the development of experimental unit 5–86, experimental and experimental units 5–84–86 and 5–88–90, as well as industrial and experimental unit 1–75–79, in accordance with the issued recommendations, previously completed productions were used as much as possible. After carrying out restoration and repair works from the previously completed workings, the workings of the irrigation horizon, located in the area of intensive influence of spent blocks, deserve special attention. In contrast to known technologies and technical means for leaching metals from rock ores, leaching and productive solutions are pumped from the lower to a higher horizon without releasing them to the earth's surface (see Table 1, bottom line).

Products are delivered to the earth's surface in carts in the form of resin for further processing at the landfill. Increasing the efficiency of mining operations in the mines of Ukraine based on the introduction of high-performance mining equipment and combined geotechnologies of the new generation makes it possible to increase the level of intensification of technological processes, mechanization of charging and detonating BP, etc. The introduction of PBV on an industrial scale will significantly improve the economic indicators of production activity, which will allow, through the modernization of fixed assets and the technical rearmament of production, to attract the reserves of poor, non-conditional and off-balance ores, to expand the available raw material base of the mining industry by 1.4–1.6 times and to extend the existence of existing mines [29].

In two-stage processing of ore, the supporting pressure is redistributed to the chambers of the second stage of processing, and the load on the structures is determined by the mass of the rocks inside the natural equilibrium of the rocks. Disturbed rocks within the vault are deformed, but can form a strong structure and not hinder the leaching process. The development of PBV ore deposits involves the creation of areas with rocks of different strength in energy-disrupted massifs: – exploitation blocks are filled with ore material that is mobile and prone to tracking, and is also characterized by water saturation and weakening of rock strength; - in the process of leaching, mineral particles move.

The creation of such areas provokes the growth of tensile stresses and load on the elements of the natural and man-made system. A balanced state of the ore-bearing massif is ensured if the PBV blocks are relieved of critical stresses by artificial and natural massifs. This method makes it possible to significantly reduce the operations used in the traditional mining system (except for those such as the creation of compensation space, release and delivery of up to 30% of stored ore from the PBV chamber, etc.). A distinctive feature of determining the parameters of the destruction of rock ores with a given quality of crushing for leaching is finding the necessary energy of the explosion, taking into account the maximum energy intensity of rock crushing. flying rocks, with subsequent ore striking in the clamp. During the experiment, about 54% of the metal reserves in the block were transferred into the solution with an acid consumption of 36% of the design value. Hardware scheme of industrial development of PBV technology was developed by NVK "A and M", manufactured jointly with the repair and mechanical plant of RMZ SE "ShidGZK", Ukraine). Technological equipment for metal leaching includes: sorption columns of the SNK type; pumping station with a capacity of 0.4 m^3 and an AH pump; composition of containers with ion-exchange resin and diluted sulfuric acid [30].

6. Efficiency

The economic efficiency of the results was determined on the basis of data on the actual cost of metal at the PBB (Table 8) according to the formula:

$E_{real} = (N_{blok} \times T_{on} \times T_{of}) \times C_{blok} - (N_{trad} \times T_{trad}) \times C_{trad}$, den. unit, (4) where N_{blok} is the amount of metal in the stored PBB ore, kg; T_{on} is the metal extraction using the ion-exchange resin, USD; T_{of} is the metal extraction from the ion-exchange resin, USD; C_{blok} is the cost of 1 kg of metal obtained from PBB, monetary units; N_{trad} is the amount of metal in an identical ore block processed using traditional technology, kg; T_{trad} is the metal extraction from the ore mined from the block using traditional technology, USD; Ct_{rad} is the cost of 1 kg of metal obtained from the ore of the block processed using traditional technology, monetary units.

Table 8.

Production volumes

Name of indicators	Indicators
Leached, t	28 284
Metal content, conventional units	0,038
Amount of metal in ore, kg	10 748
Recovery on resin, %	70,0
PBB leaching solution, kg	7 524
Recovery from resin, %	99,5
PBB productive solution, kg	7 486

The economic efficiency of implementing the recommended technology is determined according to the expression:

$E_w = [\{P - C_{blok}\ )\} \times R \times K \times T_1 \times T_2]$ *20, den. units/year, (5)

where P is the price of 1 kg of metal in concentrate, in monetary units; R is the operating reserves of poor ore, t; K is the metal content in the mined ore, conventional units; T_1 is the extraction of metal from mine PBB, in conventional units; T_2 is the plant extraction of metal from mine PBB at the mining and metallurgical plant, in conventional units; 20 is the accepted number of years of development of reserves of poor ore, in terms of the content of the useful component (see Table 8).

And at the very end, taking into account the negative consequences of the impact on human health from the action of heavy metals and radiation factors and the peculiarities of their combined impact on the population and workers of the uranium mining and mining and metallurgical industry, continue the scientific justification and development of preventive environmental and social measures to minimize them , which require an urgent solution [1], [2].

On the basis of the received positive results of the research and implementation of technologies for the extraction of metals from strong ores during the development of operational block 5-86, the prerequisites have been created for the implementation of combined technologies of underground and surface bulk leaching of metals during the development of poor ores classified as out-of-balance for the traditional method. The main indicators of block leaching are given in Table 9.

Thus, the introduction of PBB on an industrial scale will significantly improve the economic and environmental performance of production. As a result of the conducted research, it was established that mining and chemical technologies can be used to develop poor, substandard and off-balance, in terms of useful component content, ores of rock deposits, and thus increase their profitability. In order to improve the safety of mining operations of the Michurinskoye deposit in the zone of influence of the mouth of the Ingul River (Ukraine) and the cavities of spent chambers, a VAT forecast and an assessment of the conditions for the dynamic manifestation of mining pressure were performed; organization of a system of geomechanical and seismic monitoring for the stability of chamber exposures.

7. Prospective directions for further research

In order to protect the underground workings from the ingress of the waters of the Ingul River, especially during the spring flood, along the mouth in the zone of influence of mining operations, a dam was built from rocks and an anti-filtration curtain from loam to the depth of the lower limit of the weathering crust. The specified curtain performs the role of semi-active water-permeable chemically active barriers (CBA) and biological technologies, it is necessary to build an observation network of wells that controls the incoming and outgoing flows of groundwater. This ensures a decrease in the degree of metal contamination of ground and surface waters, soils and sediments [31], [32].

Table 9.

Main indicators of block leaching

Name of indicators	The value of indicators
Volume of leached ore, thousand tons	8,248
Metal content, conditions. unit	0,065
Consumption of acid H^2SO^4, i.e	231,1
Specific consumption of acid, kg/t	28,0
Consumption of acid for acidification, i.e	27,8
Specific consumption of oxidizer, kg/t	3,3
Duration of souring, days	40
The amount of solutions supplied for irrigation, m^3	66106
Irrigation density, $l/(m^2 \cdot h)$	9,6
Duration of watering, days	166
Duration of sorption, days	398

Volume of solutions for sorption, m^3	25756
Characteristics of productive solutions:	-
uranium concentration, average, mg/l	220
content of sulfuric acid, average, g/l	13,5
pH value, average	3,2
Characteristics of irrigation solutions, g/l:	-
Concentration of Fe+3/Fe+2, g/l	1.9/0.38
Mineralization (dry residue), g/l	43,2
Volume of metal-saturated anionite, m^3	101,3
Average capacity of saturated sorbitol, kg/m^3	27,3
Residual metal capacity of the sorbent after regeneration, kg/m^3	0,66
Duration of washing tails in the block, days	65
Volume of washing water, m^3	5775
Specific consumption of water for washing, m^3/t	0,7

Implementation of combined technologies, which include the organization of two specialized underground sites (the first – for beneficiation of ore; the second – operational blocks of PBV for leaching metals) and two above-ground (the first – for separation and processing of off-balance ore dumps in surface warehouses of mines on modular installations; the second – commercial leaching of metals on the earth's surface). The first section envisages the construction of an underground ore beneficiation section (PRZD) in the mine [33], [34].

The second is the organization of metals under the PBV, for conditions when rich ores are brought to the surface of the earth and processed at the HMZ, and poor and substandard ones are leached in underground PBV operational units and stacks on the surface of the earth (purchasing leaching) with the obtaining of metals, building materials, gases, acids and low-grade alkalis. The optimal combination scheme includes elements of rich ore mining with ore processing at the plant, leaching of metals from ordinary and off-balance ores in blocks and heaps, as well as enrichment tailings in disintegrators. To ensure complete extraction of metals from ores, as well as rapid cost recovery, leaching of poor ores is combined with the traditional production of metals from rich ores (Fig. 6).

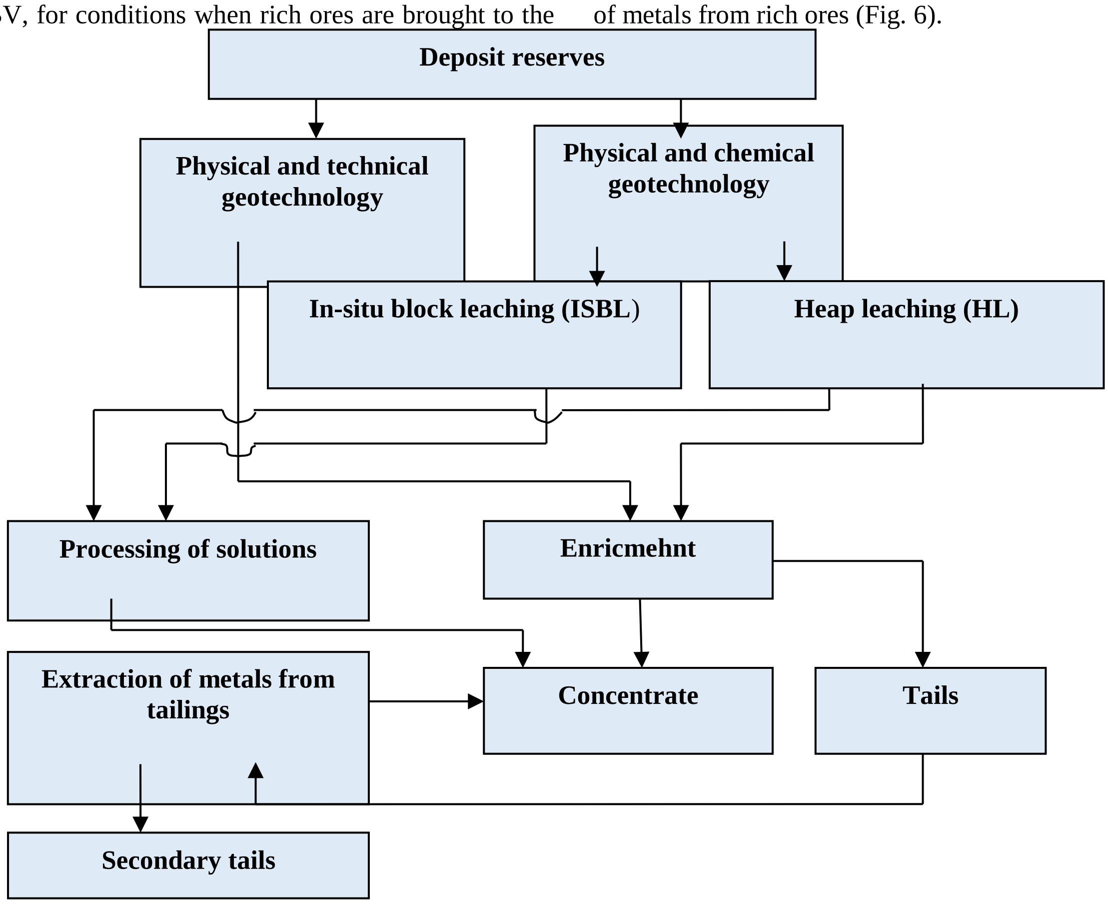

Fig.6. Algorithm for combining geotechnologies for developing ore deposits (scheme)

In our opinion, the following new scientific and methodological provisions deserve respect. In our opinion, the following new scientific and methodological provisions deserve respect:

A distinctive feature of the proposed method of determining rock destruction parameters at a given quality of grinding of strong ores for leaching is finding the necessary explosion energy, taking into account the maximum energy consumption for crushing the rock.

It has also been established that the ratio of the average linear size of a piece of crushed ore mass to the diameter of the borehole (***d_c'***), required by the condition of maximum leaching of metal, is achieved by matching the level of energy of the explosion, which is transformed into a destroyed massif, with the kinetic energy of the pieces of rock that fly apart, is a logarithmic function of the specific consumption of explosives (***q_{EV}***) for primary crushing according to the refined formula: $d_c' = -0{,}553 \ln q_{BB} + 2{,}1145$.

8.Conclusions and prospects for further development

*Conclusions.*The parameters are substantiated and rational schemes for the preparation of cleaning units are chosen during the combined development of ore deposits with chambers with a lining and PBV of metal in mining operations. In particular, technological schemes for the formation of cut-off gaps and compensation spaces are recommended to ensure optimal loosening of stored ore under the condition of leaching of metals with a loosening coefficient of 1.15 > K_r < 1.2 and structural stable parameters of the chambers: height - 20 m; width – 16 m; length - 24 m.

It is shown that the most intensive infiltration leaching occurs in the size class of ore pieces -100 + 0 mm. Metals are extracted less intensively and longer from fractions – 200 + 100 mm. PBV of metals from ores will not only significantly improve the economic indicators of production. The specified PBV technology will make it possible to extract reserves of poor and substandard ores in terms of mineral content and to expand the available raw material base of the mining industry by 1.4–1.6 times, as well as to ensure environmental safety of the combined development of strong poorly penetrated ores.

For neutralization and washing of the spent ore mass after the end of the metal leaching technology, it is proposed to supply technical water through the pipeline for irrigation of the ore massif (for PBV). Protection of the geological environment should be carried out by creating a water curtain, as well as the construction of semi-active VHAB and silting with a clay solution of the bottom of the chamber for collecting productive solutions. It is also recommended to treat with a solution of lime and mine water and to organize hydrogeological monitoring of groundwater through observation wells drilled in the bottom of the production block and to the contacts with the ore body, as well as zones of cracking and hydrogeological rupture of rocks.

It was determined that the combined technology with leaching, compared to the traditional technology, reduces metal losses during extraction by 5-10%, and during enrichment - by 2-2.5%. The introduction of the specified technology will also ensure an increase in economic efficiency and environmental safety, rational use and protection of the subsoil and hydro-geological environment. On the basis of the received positive results of the research and implementation of technologies of PBV of metals from rock ores during the development of block 5-86, in accordance with the issued recommendations, scientific support was carried out during the development of blocks 5-84-86 and 5-88-90, as well as industrial experimental block 1-75-79.

Prospective studies. Implementation of combined technologies, when rich ores are exposed to the day surface and processed at the landfill, and poor and substandard ones are leached in PBV and stacks on the surface of the earth (commercial leaching) with the production of metals, building materials, desalted water, gases, acids and low-grade alkalis. Such technologies are effective when 40% of the rich ore is released to the surface, and 60% of the poor, out-of-balance ore is leached underground. With the same productivity of the enterprise from the mining mass, the productivity from the metal doubles [35].

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