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Specifying the approaches to geoinformation monitoring to assess the development dynamics of mining enterprises as natural-technological systems

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Abstract

Introduction. *The article considers problems related to the need in a system of indicators assessing mining technological conditions variation based on mining dynamics monitoring as well as its harmful environmental impact, which is constant over an indefinite period of time. Besides, the introduction of a block of biogeochemical indicators into the general indicative system in order to develop effective methods of environmental rehabilitation is associated with the study of self-healing processes, which will allow managing these processes, thereby accelerating the formation of stable and well-functioning ecosystems.*

Research aim. *Base on the research, the article aims to determine approaches to geoinformation monitoring to assess the dynamics of mining enterprises formation as integrated natural-technological systems in order to choose a strategy for the environmentally safe development of natural deposits and technogenic mineral formations.*

Methodology. *An algorithm for assessing the dynamics of mining enterprises formation as natural-technological systems is considered as well as the main directions and tasks of geoinformation monitoring as a tool for controlling technical risks and compensating for environmental risks during the development of solid mineral deposits.*

Results. *The article considers methodological aspects of systematic assessment of natural deposits and man-made formations development projects implementation based on geoinformation monitoring data. Besides, the dynamics of mining enterprises formation as natural-technological systems is proposed to be assessed based on the ideology of modeling transient processes where the object changes its parameters from some initial (initial) to prescribed (final) by the approved design documentation. The transition process at least involves: a transformed natural system, a technological system that changes or affects the natural one, and a socio-economic system being a complex where the organizational, financial and economic activities of the enterprise are implemented in management.*

Key words: *geoinformation monitoring; geoinformation systems (GIS); transient processes; indicators; deformation background; environmental safety; technological risk.*

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Introduction. The method of systematic data assessment and geoinformation monitoring structure aimed at choosing the strategy for environmentally safe development of natural deposits and technogenic mineral formations is based on general results of previous researches [1, 2], as follows:

Table 1. Main directions and tasks of geoinformation monitoring as a tool for controlling technical risks when developing solid mineral deposits
Таблица 1. Основные направления и задачи геоинформационного мониторинга как инструмента контроля технических рисков при подземной разработке твердых полезных ископаемых

Main technical risks of industrial management	Main directions in GIS use as a tool for risk control and compensation	Tasks of geoinformation monitoring			
		Construction	Exploitation	Completion	Effect of mining
Significant amount of work on creating developed engineering infrastructure	Creating multipurpose regional GIS of the site's integrated development	Assessment of the attracted resources	Licence control	Closure project control	Negative processes monitoring
Mining loss, associated components loss during ore processing	Monitoring resources mining and mining and processing waste disposal. Monitoring the safety of the slime storage as a hazardous hydrotechnical structure	Spacing and quality control	Conditions specification, mining control	Waste recycling and conservation	Recultivation and neutralization
Violation of mine working stability and structural elements of support system. Rock-bump hazard	Monitoring the stress-strained state of mine workings and the enclosing rock. Current geomechanical safety control for stoping and preliminary development.	Current security control	Substantiating development parameters	Assessing the measures for closure	Surfaces deformation control
Surface subsidence with possible sink and cave-in	Geomechanical monitoring of surface shift caused by mining. Current voids control, location of solid stowing and washery refuse in the mine goaf	Substantiation of safe development parameters	Forecast of rock mass stress-strained state, backfilling control	Assessing the effects of closure	Assessment of beneficial use
Inrush of water into the mien workings due to rock mass undermining and lack of reliable data on hydrogeology	Hydrogeological monitoring and forecast of hydrosphere's condition under early draining and backfilling of the undermined rock mass and roadway construction	Assessing the method of dewatering and water depression control	Rock mass control and a cone of depression	Assessing the measures for conservation	Controlling the quality of groundwater potential
Lack of water resources for industrial water supply	Hydrogeomigrational monitoring of surface and underground water when managing the recycling water supply and sewage treatment	Environmental audit	Water quality control	Assessing the methods of neutralization	Spill control

Table 2. Main tasks of geoinformation monitoring aimed at compensating for environmental risks of mining
Таблица 2. Основные задачи геоинформационного мониторинга для компенсации экологических рисков отработки

Main environmental risks of industrial management	Main directions in GIS use as a tool for risk control and compensation	Tasks of geoinformation monitoring			
		Construction	Construction	Construction	Construction
Land withdrawal	Monitoring the territories with a particular regime of nature resources management and water resources protection, adjusting changes in urban development plans and other land documents	Monitoring programme	Current usage control	Perspectives for use	Change control
Soil surface disintegration	Geomechanical monitoring of the stress-strained state of the rock mass and surface displacement adding control over the hydrodynamic regime of the water-conducting strata and depressive compaction of rock	Forecast of land withdrawal	Gradual withdrawal and use	Assessing the scale and types of recultivation	Recultivation and usage control
Impact on forest, game, fishery resources	Monitoring the state of all types of lands in the vicinity of mining and monitoring recultivation measures	Status assessment	Contamination assessment	Rehabilitation forecast	Rehabilitation control
Air emissions and increase in air dustiness	Monitoring formal and informal harm sources, implementation of measures on emissions localization and long-term dust suppression	Monitoring programme	Change control	Change control	Air quality control
Geological environment alternation and the development of the zone of water conducting fissures	Monitoring a cone of depression, cave-in zone, elimination of in-situ water influxes, goaf backfilling	Monitoring programme	Change control	Status control	Rehabilitation control
Impact on surface water resources	Hydrogeochemical monitoring of drainage refinement and neutralization systems	Monitoring programme	Change control	Status control	Rehabilitation control
Waste disposal	GIS placing of solid non-toxic building waste, ferrous slags, including the ones suitable for goaf backfilling	Monitoring programme	Control of aggregation and usage	Recultivation technologies	Processing and neutralization control

– mining industry's mineral-resource base (MRB) should be understood as the system of mineral resources and methods of their production and processing, so the strategy of subsoil resources exploitation at the country, region or enterprise levels should be based on MRB primary causes study and assessment;

– the structure of the updated cadastral data has been assessed and developed, the specifications have been substantiated for natural and technogenic facilities GIS implementation, access hierarchy has been established, and the structure of a regional GIS web portal has been proposed;

– the local version of GIS "Integrated exploitation of natural and technogenic resources of the Urals" has been developed, the generalized parameters of a function prototype of GIS user's workplace have been substantiated. On this basis, the idea has been proposed of creating geoinformation subsystems "Natural and subsoil safety" and "The forecast of quality indicators of the produced raw material in the systems of ore dressing".

Approbation of the proposed methodology for targeted search and generation of options for the sequence of deposits mining, development and exploration, as well as the recommended general decision-making procedure for such strategies formation, indicate that the complex studies based on advanced or parallel assessments are the basis for control actions reasonable development. These estimates prove the efficiency of GIS which forms the total of predictive, design, reference, analytical, expert, and other data to deal with various social-economic and other problems.

Analysis and discussion. Mining projects implementation goes along with the elaboration of mining operations plans with various depth of prediction. Apart from the capital construction program itself and basic activity, which is mineral production, the plans establish a set of actions compensating for technical, economic, ecological and social risks of field development accompanying the process of mining within the whole "productive life" of a mining enterprise. The following processes are distinguished: "steady processes" which better characterize the established production regime, "stabilization processes" mainly aimed at coordinating the enterprise's work with external conditions, and "transition processes" which characterize the tactic and strategy of the mining complex's development when passing to the next work stage.

The basic system attribute of transition processes is their temporal development. Another system attribute is the presence of isolated systems interacting temporally: natural, technological and socio-economic. These systems interaction is accompanied by resistance to mutual influence and interference, therefore it is important to control certain indicators' deviation from the ones established at the stage of designing projects and mining plans, i. e. it is essential to carry out monitoring.

The strategy of waste management which uses the distributed data of regional monitoring is also definitely crucial in field development as opposed to point data from a particular enterprise never providing reliable results. New methods, such as remote sensing and GIS make it possible to adequately assess all the risks of mineral development in the region [3].

Economic risks of fields development projects implementation are the following: lack of funds for construction, expansion, reconstruction, technical upgrade and other investment, considerable investment into redemption of lands and transferring them into the category of industrial lands, lack of current assets for loan repayment, competitive opposition of one-field miners, etc.

New fields development and operation are accompanied by the elaboration of measures on social problems regulation associated with the absence of professional personnel to carry out mining and dressing, need to create residential accommodation for workers, interaction with local population on various issues including lands redemption right up to reacting to social-ecological opposition like "Stop GOK".

Tables 1 and 2 show the main tasks of iron-ore deposit development by underground technique as well as the corresponding measures based on the geoinformation monitoring and compensating for technical and ecological risks. Data from the tables prove that the tasks of monitoring change over time according to the stages and order of industrial development investment, from the starting point of construction to completion of work including the post-production period.

Besides, some technical and ecological engineering tasks aimed at improving affordability, safety and environmental friendliness of production complement each other, consequently, geoinformation monitoring of mining production should be integrated.

The method of mining territory geoinformation analysis based on marking out areas (zones) by the types of "technogenic damage" and providing situational assessment of georesources and geosystems is proposed to be considered basic when solving the problems of systematic assessment of technogenic impact made by mining enterprises. It is crucial to develop and substantiate the criteria for state estimation of mining territories as natural-technological systems at various stages of their productive life.

A priority of mining complex development is not only to improve the efficiency of mineral extraction compensating for the constantly deteriorating mining and geological conditions of mining, but also protect the personnel and people living nearby. In this regard, it appears relevant to form a system of indicators assessing the variation of mine-technological conditions of mining based on monitoring mining dynamics and harmful environmental impact which is constant over an indefinite period of time.

Large-scale mineral development inevitably breaks the stress-strain state of rock mass due to the formation of pit space, underground permanent roadways, development headings, and stopes in mine workings. Deterioration of mine-geological conditions also happens due to the fact that mine workings intersect active tectonic structures; not only rock movements develop along these intersections, but groundwater also runs actively through them.

The main and often the only source of data on the initial and anthropogenically induced stress-strain condition of rock mass are in-situ measurements of movement parameters [4–6]. In this case, under rock movement, a phenomenon accompanying mineral production, is understood the whole complex of deformation processes within the rock mass when the initial stress-strained state is formed beyond mining impact area and its transformation within the zone.

The main factors determining the development of the stress-strained state of the rock mass are the following: hierarchical-blocky structure, constant mobility, restructuring, and concentration of contemporary geodynamic displacements on the borders of the structural blocks.

In the course of mining, redistribution of mases in the subsoil is inevitable: extraction of minerals from the subsoil, gangue storage in damps, and washery refuse storage in tailing storages. Geomechanical control covers shift troughs during underground mining, while during opencasting it covers marginal rock mass, damps and tailings dams.

When a mining enterprise is liquidated, due to the abrupt change in the hydrogeological mode, recultivation, particularly connected with goaf area filling with overburden rock or washery refuse, the stress-strained state changes again accompanied by the corresponding deformations which may result in engineering structures and facilities damage [7].

When tunneling underground mine workings and stopped excavation of minerals at large depths, it is crucial to monitor the stress-strained state of the mine workings and the enclosing rock mass which is carried out by both direct and remote mine surveying and geodesy observation, and geophysical methods. Main methods of control and acquisition of data on the state of both undisturbed rock mass and anthropogenically induced rock mass are in fig. 1.

Instrumental record of changes in the deformational background of the territory and the elements of engineering structures make it possible to timely take some measures and prevent integrity violation. Control indicators in these control methods are changes in the stress-strain state by the size and direction of action, changes in the amount of unfilled voids, and development of weakness surfaces within the rock mass recorded by the geophysical methods.

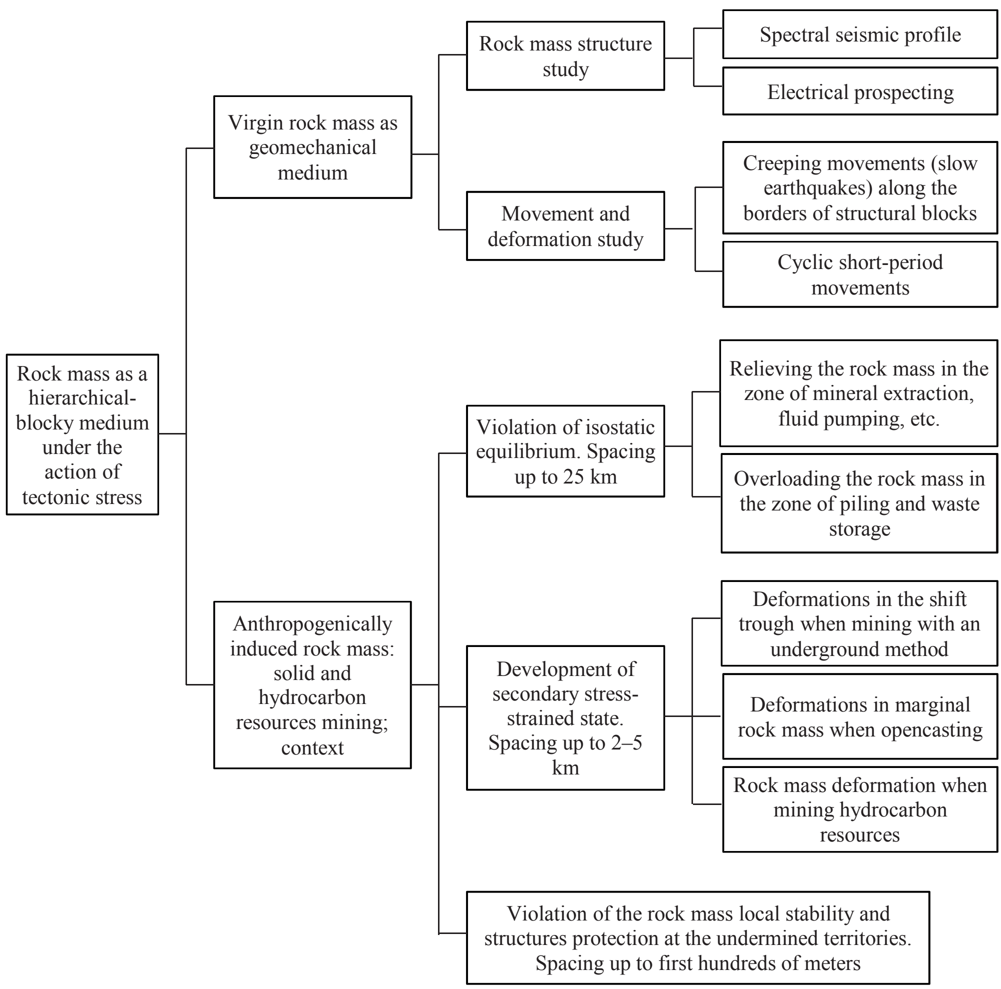

Fig. 1. Basic methods of controlling and obtaining data on the state of virgin rock mass and rock mass which has been changed by a human
Рис. 1. Основные методы контроля и получения данных о состоянии ненарушенного и техногенно измененного горного массива

The large scale of operations on the subsoil development results in significant increase in the cost of disturbed land recultivation. Therefore, the main task is to reduce disturbed lands both during mineral production and in the period of ecological rehabilitation of natural complexes [8, 9]. Techniques of methodological approach to efficient waste management when organizing the winning complex are shown in fig. 2.

It is known [10, 11], that the process of natural soil formation renews or continues in landscapes disturbed by the technogenic impact, even if the impact hasn't been terminated. If disturbed land is out of use, natural regeneration processes rehabilitate topsoil which fulfills all ecological functions, as early as within the first decades.

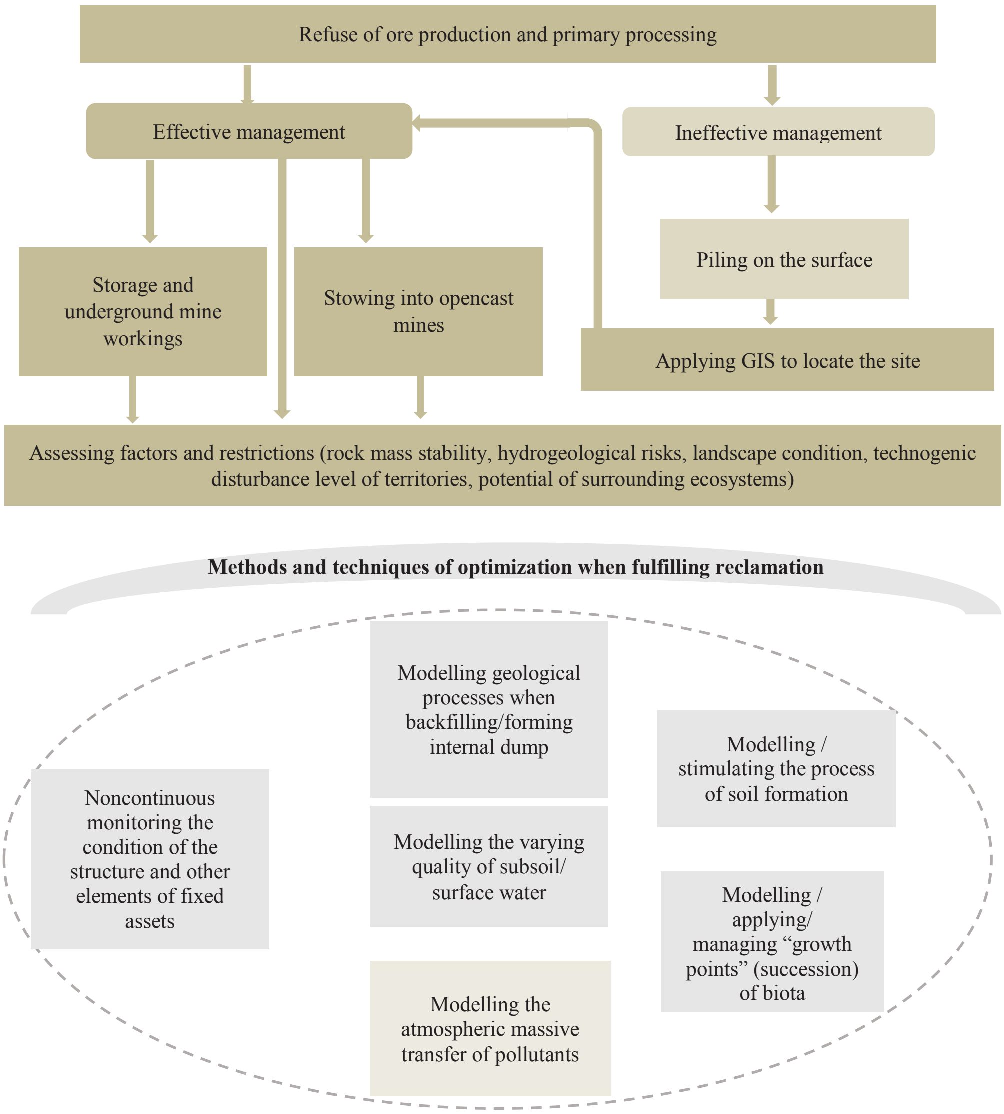

Fig. 2. Techniques of optimizing reclamation with the use of GIS
Рис. 2. Приемы оптимизации рекультивационных работ с использованием ГИС

Consequently, a link in the indicative system is a block of biochemical indicators which is characteristic of both terrestrial ecosystems degradation during active mining and their self-rehabilitation at completion and termination of field mining. Besides, the development of a block of biochemical indicators will make it possible to get an idea of natural-technological systems' stability potential when implementing the strategy of their ecological rehabilitation.

Assessing the stability of natural-technological systems, the factor of vegetation availability should be taken into account, as well as its structure, functioning, and dynamics. Today, data for landscape alternation analysis for stability assessment can be obtained by remote methods which make it possible to get enough information on the state of large technogenic systems at vast areas for a period of time sufficient for the analysis (5–15 years). An example of progress made in natural regrowth is given in fig. 3.

When fulfilling ground survey, it is reasonable to be guided by the results of assessment of biochemical processes in anthropogenically damaged ecosystems in mining enterprises territories as soon as naturally regrowing ecosystems represent continuous biogeochemical process of natural purification which involves ecosystem's natural reserves: climate, microbiology, and landscape-geochemistry.

a *b*

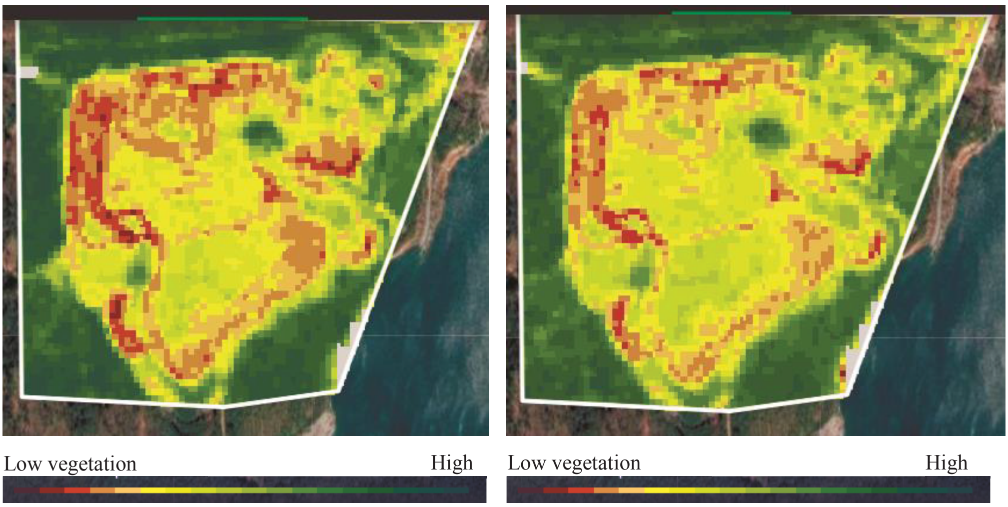

Fig. 3. NDVA index variation of the dump of Valuevsky iron ore deposit:
a – July 2016; *b* – July 2020.
Рис. 3. Изменение индекса NDVA отвала Валуевского месторождения железных руд:
а – июль 2016 г.; *b* – июль 2020 г.

As soon as soil CO_2–gas exchange is a powerful ongoing factor of soil formation, and accepting it as a basis in biogeochemical indicators analysis it is possible to forecast biota's self-regeneration [12]. Based on systematic change in soil gas condition, it is possible to forecast the base-exchange capacity and rehabilitation potential of artificial ecosystems formed at the sites of man-made objects, especially during loading stabilization and mining completion.

Consequently, the introduction of a block of biogeochemical indicators into the general indicative system in order to develop effective methods of ecological rehabilitation is associated with the study of self-rehabilitation processes; it will make it possible to manage the indicated processes accelerating the development of stable and well-performing ecosystems.

Summary. The dynamics of mining enterprises formation as natural-technological systems is proposed to be assessed based on the ideology of modeling transient processes where the object changes its parameters from some initial (initial) to prescribed (final) by the approved design documentation. The transition process at least involves: a transformed natural system, a technological system that changes or affects the natural one, and a socio-economic system being a complex where the organizational, financial and economic activities of the enterprise are implemented in management.

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О подходах к геоинформационному мониторингу с целью оценки динамики формирования горных предприятий как природно-технологических систем

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Реферат

Введение. *В статье рассматриваются вопросы, связанные с необходимостью формирования системы индикаторов, оценивающих изменение горно-технологических условий разработки на основании мониторинга динамики горных работ и негативного воздействия на окружающую среду, которое является постоянным на протяжении неопределенно длительного промежутка времени. Кроме того, внедрение блока биогеохимических индикаторов в общую индикативную систему с целью разработки эффективных методов экологической реабилитации связано с изучением процессов самовосстановления, что позволит управлять данными процессами, тем самым ускоряя формирование стабильных, хорошо функционирующих экосистем.*

Цель работы. *На основании выполненных исследований определить подходы к геоинформационному мониторингу с целью оценки динамики формирования горных предприятий как единых природно-технологических систем для выбора стратегии экологически безопасного освоения природных месторождений и техногенных минеральных образований.*
Методика. *Рассмотрен алгоритм оценки динамики формирования горных предприятий как природно-технологических систем, основные направления и задачи геоинформационного мониторинга как инструмента контроля технических рисков и компенсации экологических рисков при отработке месторождений твердых полезных ископаемых.*
Результаты. *В статье рассмотрены методологические аспекты системной оценки осуществления проектов освоения природных месторождений и техногенных объектов, реализующиеся на основании данных геоинформационного мониторинга. Кроме того, оценку динамики формирования горных предприятий как единых природно-технологических систем предлагается основывать на идеологии моделирования переходных процессов, в которых объект изменяет свои параметры от некоторых исходных (начальных) до предписанных утвержденной проектной документацией (конечных). При этом в переходном процессе как минимум участвуют: трансформируемая природная система, технологическая система, изменяющая природную или влияющая на нее, и социально-экономическая система – комплекс, на территории которого реализуется организационно-финансовая и хозяйственная деятельность предприятия.*

Ключевые слова: *геоинформационный мониторинг; геоинформационные системы (ГИС); переходные процессы; индикаторы; деформационный фон; экологическая безопасность; технологический риск.*

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