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Regulation of the Level of Safety

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Abstract. *Rationing the level of safety of work shifts is a multifaceted problem, since it must be decided on the basis of technical, economic, moral and socio-political aspects. The requirements of the risk level, arbitrarily close to zero or zero, seem unrealistic, since it requires infinitely high costs when creating a technological facility and a mine as a whole. In addition, when distributing investments, it is necessary to take into account not only the costs of ensuring safety, but also ensuring the reliability and targeted efficiency of the technological site and the mine as a whole. All these components are quite rigidly interconnected. When varying the design characteristics of reliability and target efficiency, secondary changes in the technological parameters of the object can be observed. Thus, an increase in the reliability of process equipment and control systems due to redundancy causes changes in the design balance of costs for operating the facility, that is, an event aimed at improving safety can ultimately lead to its reduction.*

Keywords: *safety, safety improvement, contingency, emergency, work shift, personnel, risk, mine, frequency rationing, reliability.*

Introduction. An event aimed at improving safety leads to its decrease [1]. Achieving an acceptable balance between the characteristics of efficiency, safety, reliability and cost within the design constraints leads to the fact that the level of risk will have a well-defined minimum, different from zero.

When rationing the level of safety of work shifts, the following factors should be taken into account [2]:

- the general level of development of equipment and technologies in the coal industry;
- the number of work teams;
- the frequency of use of technological equipment and control and management systems;

Fundamentally, there are two approaches to normalizing the level of safety: normalizing the frequencies (probabilities) of the occurrence of emergency situations during a work shift and a quantitative indicator of the safety level of a work shift.

Normalization of frequencies (probabilities) of occurrence of emergency situations in a work shift.

With this approach, any emergency situation that occurs during a work shift is considered from two points of view: the danger of its consequences and the permissible frequency (probability) of its occurrence.

According to the degree of danger, emergency situations can be divided into the following groups: those that complicate the execution of the technological map, dangerous, emergency and catastrophic [3].

From the point of view of the possibility of occurrence of emergency situations, it is customary to distinguish five main levels of the frequency of their occurrence (per 1 hour of a work shift): repetitive, moderately probable, unlikely, extremely unlikely, and practically unbelievable.

The meaning of normalization is reduced to a qualitative comparison of the degree of danger of emergency situations with the frequency (probable) of their occurrence: the more dangerous the situation, the lower the permissible frequency of its occurrence (Table).

The frequency values indicated in Table 1 may correspond to the following repeatability of the indicated ES:

- recurring ES may occur one or more times during the work shift;
- Moderately probable ES may not occur in one work shift, but may occur several times during the operation of a given technological facility;
- unlikely ES may not occur at all or occur a single number of times during the operation of an object of this type;
- extremely improbable ES may appear during the operation of the technological facility as an exceptional phenomenon;
- practically unbelievable ES should be considered as impossible from the point of view of their occurrence in a given technological facility during its operation.

The main disadvantage of this method of

Frequency levels of occurrence of an emergency situation (ES)		
Type of ES	**Frequency levels of occurrence of ES**	**Frequency range λ of ES, hour⁻¹**
ES, causing complication of the execution of the technological map	Recurring	$\lambda \geq 10^{-3}$
	Moderately likely	$10^{-7} \leq \lambda \leq 10^{-3}$
Dangerous	Unlikely	$10^{-7} \leq \lambda \leq 10^{-5}$
Emergency	Highly probable	$10^{-9} \leq \lambda \leq 10^{-7}$
Catastrophic	Almost unbelievable	$\lambda < 10^{-9}$

normalization is that when normalizing the frequency (probability) of the occurrence of ES, the level of safety is not directly quantitatively normalized [4].

Normalization of the quantitative value of the indicator of the level of safety of the work shift.

With this approach, the level of safety of work shifts is quantified using a specific indicator. In this case, two circumstances should be taken into account:

1) for technical design, it is more convenient to implement the work shift safety standard if it is given in a probabilistic form;

2) in operation it is more convenient to control the fulfillment of the norm by various statistical indicators [5].

To resolve these contradictions, one should use the known relationships between probabilistic and statistical indicators of work shift safety.

Most often, the probability P_r of the crew's safe return to the surface during the process of performing the technological map is taken as the criterion for the safety of the work shift. The starting position in this case is that during the implementation of technological operations, three independent outcomes are possible that make up a complete group of events:

1) execution of the technological map and a safe exit to the surface (probability of the event P_e);

2) premature (emergency) termination of the work shift at some stage and the safe return of personnel to the surface (probability of the event P_a);

3) emergency termination of a work shift with a catastrophic outcome (probability of the event P_k).

Based on this, $P_e+P_a+P_k=1$, a $P_r=P_e+P_a$.

Other probabilistic and statistical indicators can also be used to assess the safety of a work shift [6].

The choice of the quantitative value of the normalized indicator is based on the following principles: the level of safety of the designed technological object must be higher than the achieved level of safety for a similar object that has been in operation for a long time or has been in operation for a significant time; it should be noted that such a principle is competent if at least three conditions:

- a new technological object according to its scheme does not fundamentally differ from an analogue object;
- for a new object, approximately the same operating conditions are assumed as for an analogue object;
- for the forecasting period, which takes into account the time of design, installation, commissioning, testing of a new facility, no abrupt change in the level of safety is expected [7].

The forecasting technique is based on the extrapolation of actual data and boils down to the following.

Let $\widehat{y_c}$ be a normalized work shift safety indicator. Its values y_t are known for the object – analogue, $t=1, 2, ..., n$ – the calendar time of its operation (observation interval). It is required to determine the predicted value of the indicator y_{n+L} from these data, where L is the forecasting interval (leading period). For this, the time series y_t is represented by a model of the form

$$y_t = \widehat{y_t} + \varepsilon_t,$$

where $\widehat{y_t}$ – a trend that characterizes the dynamics of changes in an indicator on average; ε_t – component characterizing random fluctuations of the indicator over periods of operation.

The function describing the trend is chosen, as a rule, in the class of polynomial functions

$$y_t = a + \sum_{j=1}^{k} b_i t^j .$$

The unknown parameters a and b_i of the function can be determined from the statistical data y_t by the least squares method or its modifications: exponential smoothing, probabilistic modeling, adaptive smoothing.

The predicted value of the indicator y on average at the time of forecasting $t=n+L$ (point forecasting) is as follows:

$$\widehat{y_{n+L}} = a + \sum_{j=1}^{k} b_j (n+L)^j .$$

This forecast will contain an error related to the known uncertainty of the position of the trend $\widehat{y_t}$ and possible deviations ε_t from this trend. Therefore, along with point forecasting, interval forecasting is used, in which a confidence interval is calculated for the predicted value of the indicator

$$\widehat{y_{n+L}} \pm t_\alpha S_p,$$

where S_p – forecast mean square error; $t_\propto$ – tabular value of Student's t – distribution; $\propto$ – significance level.

It should be noted that forecast errors significantly depend on the ratio of the lead interval L to the observation interval n. The larger these ratios, the larger the prediction error.

Rationing of safety requirements for the elements of a technological object.

Rationing or distribution of safety requirements to the elements of a technological object based on the provision of a given value of the safety level indicator at the object as a whole is carried out by the method of successive approximations [8]. At the same time, they proceed from the concept of creating an «equivalent» system without weak links and excessive «reserves». It is important that all resources are used rationally to achieve the best possible work shift safety.

In general, the sequence of solving the problem of safety standardization for the elements of an object can be represented as three operations:

1) structural analysis of the elements of objects and assessment of their contribution to the overall safety indicator, using data by analogy at the level of units, products, control and management systems;

2) analysis of the sensitivity of the output indicator to changes in the reliability parameters of the equipment of the object in a certain range and assessment of the corresponding necessary and available objects;

3) comparing options and making a decision to ensure that the requirements for the level of target efficiency and safety of the work shift are met.

In practice, the problem of normalization is solved by calculating the initial base case, for which all parameters of process equipment and monitoring and control systems are selected and linked, and consistent satisfaction of the requirements of target efficiency and a safe work shift [9]. Satisfaction with safety requirements is carried out last, since, as a rule, they are the most stringent. Consistent satisfaction of the listed requirements is carried out by a gradual increase in the reliability of equipment and control systems of a technological object with a certain step (due to the introduction of redundancy, changes in schemes and modes of operation, additional development of a technological map, etc.), with an assessment of the increment in the reliability of each element of technological equipment and systems control and management and its correlation with the corresponding costs. Then, the analysis and determination of the most advantageous solution to improve the characteristics of a certain element of the facility's equipment is carried out. This iterative procedure is repeated until the condition for achieving the specified value of the safety indicator for the technological object as a whole is met.

Rationing safety by setting quality requirements.

Qualitative requirements for ensuring the safety of the work shift are an addition to quantitative requirements [10]. They cover such areas of safety as: organizational measures, design principles and design solutions, the composition and characteristics of safety equipment, the choice of materials, the distribution of functions between the personnel of the technological facility, the dispatch service, monitoring and control systems in emergency situations, taking into account the impact of adverse factors, information support for the personnel of the facility, ways to control the functioning of technological equipment, stocks of consumables and spare parts.

Conclusions. These requirements are a reflection of the accumulated experience in ensuring the safety of work shifts and are subject to mandatory implementation in the process of creation, installation, commissioning, testing and operation of a technological facility. They cover all elements of a technological facility and all stages of its creation and operation and are designed to regulate: principles, necessary conditions and methods for ensuring safety; types and procedure for carrying out work to ensure safety; composition, purpose, procedure for engagement and operation, as well as conditions for the use of security equipment; operational restrictions imposed on the use of process equipment and supervisory control facilities; tasks and methods of control, the composition of the controlled parameters that determine the safety of the personnel of the brigade, and ways to inform the personnel about the achievement of their limit values; layout, equipment, design features and placement of technological equipment of the facility in order to ensure safety; appointment and placement of emergency supplies at the facility; properties of consumables that ensure the safety of their use in the process of performing the technological map, the procedure for their admission to use in the work shift, the procedure for activities, the interaction of team members among themselves and with the personnel of the dispatch service in the interests of ensuring safety.

Taking into account the technical orientation of these requirements, in their composition and content they significantly depend on the type of process facility, the level of development of process equipment and monitoring and control systems, the accumulated experience in ensuring safety, and therefore should be set for a specific process facility, taking into account the listed factors.

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Қауіпсіздік деңгейін реттеу

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***Аңдатпа.** Жұмыс ауысымының қауіпсіздік деңгейін бағалау көп қырлы мәселе болып табылады, өйткені оны техникалық, экономикалық, моральдық және әлеуметтік-саяси аспектілер негізінде шешу қажет. Тәуекел деңгейінің талаптары, нөлге немесе нөлге ерікті түрде жақын, шындыққа жанаспайтын сияқты, өйткені ол технологиялық нысанды және тұтастай алғанда шахтаны құру кезінде шексіз жоғары шығындарды талап етеді. Сонымен қатар, инвестицияларды бөлу кезінде қауіпсіздікті қамтамасыз ету шығындарын ғана емес, сонымен қатар технологиялық алаңның және тұтастай алғанда шахтаның сенімділігі мен мақсатты тиімділігін қамтамасыз етуді ескеру қажет. Бұл компоненттердің барлығы бір-бірімен өте тығыз байланысты. Сенімділік пен мақсатты тиімділіктің жобалық сипаттамаларын өзгерту кезінде объектінің технологиялық параметрлерінің қайталама өзгерістерін байқауға болады. Осылайша, технологиялық жабдықтың және басқару жүйелерінің артық болуына байланысты сенімділігінің артуы объектіні пайдалану шығындарының жобалық балансының өзгеруін тудырады, яғни қауіпсіздікті арттыруға бағытталған оқиға, сайып келгенде, оның төмендеуіне әкелуі мүмкін.*

***Кілт сөздер:** қауіпсіздік, қауіпсіздікті жақсарту, күтпеген жағдай, төтенше жағдай, жұмыс ауысымы, персонал, тәуекел, шахта, жиілік нормасы, сенімділік.*

Нормирование уровня безопасности

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***Аннотация.** Нормирование уровня безопасности рабочих смен представляет собой многоплановую проблему, поскольку оно должно решаться исходя из технических, экономических, моральных и социально-политических аспектов. Требования уровня риска, как угодно близкого к нулю или нулевого, представляются нереалистичными, так как требует бесконечно больших затрат при создании технологического объекта и шахты в целом. Кроме того, при распределении инвестиций необходимо учитывать не только затраты на обеспечение безопасности, но и на обеспечение надежности и целевой эффективности технологического участка и шахты в целом. Все эти составляющие достаточно жестко взаимосвязаны между собой. При вариации проектных характеристик надежности и целевой эффективности могут наблюдаться вторичные изменения технологических показателей объекта. Таким образом, увеличение надежности технологического оборудования и систем управления за счет резервирования вызывает изменения проектного баланса затрат на*

эксплуатацию объекта, то есть мероприятие, направленное на повышение безопасности, может в конечном счете привести к ее снижению.

Ключевые слова: *безопасность, повышение безопасности, нештатная ситуация, аварийная ситуация, рабочая смена, персонал, риск, шахта, нормирование частоты, надежность.*

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