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Technical and organizational measures and means of ensuring the safety of the production process

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The organization of a safe environment at the enterprise is formed up not only due to the perfection of safety regulations and their observance, but also due to the fact that all the proposed safety measures are fully consistent with production needs and can be considered as a function of ensuring the development of production. The relevance of the study is determined by the fact that the use of modern systems for the formation and establishment of the safety of the production process allows you to boost production activities and positions of the enterprise in the foreign market. The novelty of the study is determined by the conformity of the proposed regulatory indicators and the form of their approval at the enterprise. The authors put the mathematical model at the basis of the proposed indicators, which corresponds to the main decisions of modern quality standards. The article shows the possibility of determining diversity and the formation of requirements that are recommended for implementation based on operational indicators of the enterprise. The authors present a mathematical and graphical model for integrating safety requirements into the overall structure of the production process. The practical significance of the study is determined by the possibilities of the formation of individual requirement parameters for ensuring the safety of the production process for local industries.

Keywords: enterprise, probabilistic assessment, numerical methods, uncertainties, modeling

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INTRODUCTION

The problem of estimating uncertainties has been and remains one of the key issues for discussion at specialized international scientific conferences: probabilistic safety and management assessment conducted by the International Association of Probabilistic safety and management assessment; probabilistic assessment and safety analysis by the American Nuclear Community (Brown 2002). The topic of uncertainty assessment also does not go unnoticed at international scientific conferences (Huang et al. 2019). As part of the study, an analysis of the materials of PSAM/PSA conferences in recent years was carried out, as well as other scientific publications and reports on the subject of uncertainty assessment (Wang & Shao 2010). Based on the analysis, the following may be noted (McLain & Jarrell 2007):

– the following are seen as promising mathematical theories for estimating uncertainties: probability theory, theory of possibilities, theory of fuzzy sets, interval analysis;

– the issue of separation of aleatory and epistemological uncertainties using numerical methods (the two-phase Monte Carlo method) is considered, however, no consensus has been reached on the separation of uncertainties;

– individual studies are aimed at establishing correlation coefficients between input parameters and output value (for example, studies are conducted using the SUSA calculation code to estimate model uncertainty);

– the importance of identifying sources of uncertainties and their consideration in decision-making is noted in international publications.

Constraining factor for the wide practical use of the methodology of probabilistic safety modeling of complex technological systems is significant resource for the development of computational models without the use of software tools (Akkarawatkhoosith et al. 2019). This is due to the following (Zhao et al. 2007): a large number of system elements (basic elements); exponential dependence of the dimension of models on the number of elements; high structural complexity of real systems, limited typical fragments for decomposition of systems; dynamism of the modeling process. The only solution to the problem of dimensionality of models and optimization of resources for model development is the automated technology of probabilistic modeling (Byrd et al. 2018). In general, modeling automation provides (Fan et al. 2013): full formalization and practical implementation of computer-aided presentation of structural schemes of systems and criteria for their functioning; the use of algorithms and software implementation of all processes of converting structural schemes and criteria into the corresponding computational mathematical models of systems.

THEORETICAL OVERVIEW

The security document must contain a reliable and evidence-based basis, for this it is necessary to ensure the possibility of updating it as: equipment modifications; receiving feedback from internal and external operating experience;

in-depth understanding of production processes or the development of an accident and improvement of modeling techniques. The update is necessary to take into account: design changes; operational changes; organizational changes. The frequency of updating the document on safety and standardization, adopted in international practice, varies for different enterprises. However, it is very important to monitor all changes that occur and evaluate their impact on the results of risk monitoring. If the changes are significant, you will need to update the security and standardization document as quickly as possible (Liping & Yun 2015). Typically, design models are updated after scheduled maintenance repairs (SMR); full documentation updates can be done later (Polukarov et al. 2020, Levchenko & Polukarov 2020).

Since each modification of the enterprise is evaluated as it is introduced, it is recommended not to accumulate a package of such ratings for a period of more than one year. In the absence of modifications that require changes to the models of safety and standardization document, the update is carried out at least once every four to five years. The safety and standardization document should be updated at each time it is used to justify changes to the licensing basis (Zhai et al. 2013). To ensure an adequate representation in the enterprise model, the update is performed after the modification of the enterprise. After each modification, the terms for updating the security and standardization document and data documentation are set depending on the impact of the modification on the enterprise security level (Kruzhylko et al. 2017). Documentation of data can be divided into two main areas: documenting the source data on the performed modifications of the enterprise and documenting the results of viewing the document on safety and standardization in case of an urgent and scheduled update (Lv & Zhang 2014). When documenting the source data of enterprise modifications, all modifications must be documented in the update materials. In case of significant changes, it is possible to develop a new version of the relevant document on safety and standardization. Regardless of the significance of the modification, it is necessary to update all the databases used in the safety and standardization document to display the current status of information regarding the enterprise (Pei & Liu 2019).

To develop and update a document on safety and standardization, an enterprise must have a permanent group (or unit) of engineering personnel consisting of (at least): system analysis engineer; data analysis engineer; engineer for the analysis of personnel reliability; software engineer – specialist in the development of programs based on the analysis of mathematical, as well as other probabilistic models. The quality of work performed as part of the implementation of the safety and standardization document should be ensured taking into account the requirements of quality assurance instructions in the analysis and assessment of safety. The manuals, procedures and instructions used in the work should contain quantitative and qualitative criteria for acceptability to ensure that important actions are performed satisfactorily in accordance with accepted standards and methods.

MATERIALS AND METHODS

Uncertainty estimation methods can be simplified into two groups:

1. Statistical methods. These are methods of probability theory, which are based on the fact that inaccuracies in the input parameters are probabilistic in nature, that is, their values have a certain probability density distribution function with corresponding numerical characteristics. Combinations using a random number generator of probabilistic values of input parameters lead to probability density distribution functions of the possible value of the resulting parameter, when its deviations are also probabilistic in nature.

2. Analytical methods. These are methods based on various mathematical theories: the generalized perturbation theory method, the sensitivity method, the quantile estimation method, the fuzzy set theory method.

Today, statistical methods are dominant in the process of estimating uncertainties. Their algorithms and mathematical models are well developed and implemented in probabilistic calculation codes (SAPHIRE, RiskSpectrum). Analytical methods can be considered as an alternative to traditional statistical methods. At the same time, the use of analytical methods for estimating uncertainties is limited due to the need to adapt mathematical theories to solve practical problems of safety documentation and standardization. Promising is the application of the theory of fuzzy sets. The application of the theory of fuzzy sets in the analysis of system reliability and the construction of the enterprise modernization process is developed in foreign publications, and work is also being carried out in a number of technology companies in the same direction.

Of particular interest is the two-phase Monte Carlo method, with which you can highlight the aleatory and epistemological uncertainties. When using the two-phase Monte Carlo method, the uncertainty of equipment unavailability is estimated, which is a function of two quantities: failure rate (λ) and recovery rate (μ). The inner loop of Monte Carlo statistical modeling corresponds to the aleatory uncertainty (randomness of failure time and recovery time – exponential distribution), the outer loop corresponds to epistemological uncertainty (inaccuracy in estimating equipment failure time and recovery time – lognormal distribution). For each iteration of the calculation, the values of the parameters in the external loop are randomly selected from the given distribution and transferred to the internal loop. In the internal loop, random values of time to failure and recovery time are generated, taking into account which the system logic is calculated. For each iteration in the inner loop, the distribution of system unavailability is constructed, which takes into account the stochastic nature of failures and system recovery. The result of a given number of iterations is a family of distribution curves, where each curve characterizes the aleatory uncertainty, and the family of curves is an epistemological one.

Based on the results of a literature review and a study of the current state of the problems of uncertainty assessment, it is concluded that there are no principles of risk information decision-making in the national regulatory framework (Mokoena & Oberholzer 2015). The work is dedicated to filling this gap in the regulatory framework (Dyrdonova et al. 2018). The basic principles that are presented later were introduced in the regulatory document (Sato et al. 2011). The objectives of risk-informed decision-making on the safety of facilities were originally formed (Li-Ping & Jian-Yuan 2014):

– improving security by identifying and considering factors that have a dominant influence on security and implementing measures to improve security;

– a comprehensive assessment of the impact of decisions on safety, taking into account the results of risk assessments in addition to deterministic assessments and operating experience;

– optimization of operation due to the concentration of resources on the factors dominant in terms of their impact on safety, structures, systems and elements;

– a reasonable reduction in the excess conservatism and restrictions that were taken into account when developing the project and the safety justification.

Risk-informed decision-making can increase safety and reliability, reduce personnel impact and increase operational efficiency by (Tan et al. 2010): identifying and eliminating safety problems; improving and optimizing maintenance, repair and testing of structures, systems and components in order to ensure their reliability sufficient to maintain the achieved level of safety; focusing on structures, systems and components that have a dominant influence on safety (Saurin et al. 2004).

The existing relationship between the methodology of probabilistic and deterministic safety analysis is demonstrated by the example of the implementation of a strategy for the sustainable functioning of an enterprise (Jung et al. 2008). The quantitative criteria developed for making risk information decisions are to reduce the need for risk information decisions, described later (Schwartz & Rogers 1996). The adoption of risk-information decisions on the introduction of modifications important to safety regarding current procedures and technical regulations is permitted provided that this does not lead to an increase in the production cycle or an increase in the deterioration of the socio-economic situation of enterprises. At the same time, the implementation of risk-informed decision-making is allowed only if corrective measures are implemented that belong to the same security function as the decision itself and ensure that the current risk values are not exceeded.

To implement practical tasks using risk-information approaches, the following probabilistic indicators are recommended when making decisions:

– when assessing and ranking violations in the operation of enterprises for their detailed analysis and development of appropriate corrective measures, those violations in the operation of the enterprise are selected in which the conditional probability of the violation becoming a serious accident is 10^{-3} or more;

– to optimize maintenance programs, as well as support inspection activities when ranking the structures, systems and elements of an enterprise by their impact on safety, the values of probability indicators are used as criteria of high significance.

RESULTS AND DISCUSSION

Consider the problem of verifying the compliance of probabilistic safety indicators with regulatory criteria in a general statement. Let there be some safety indicator and its maximum permissible value (normative safety criterion). The condition for observing the safety criterion is written as follows (Eq. 1):

$$x_0 \leq x_{add} \tag{1}$$

Equation (1) describes the deterministic situation of the analysis, when it is assumed that there is an exact value of the safety indicator x_0 and unconditional compliance (or non-compliance) with the criterion. The presence of uncertainty in the value is acceptablex_0 and we will consider x_0 as the mathematical expectation $x_0 = M[x]$ of a random variable x distributed according to one of the known distribution laws with a probability density $f(x)$ by distribution function $F(x)$.

The probability that the random variable does not exceed the maximum permissible cell value x_{add}, will be determined by the value of the distribution function (Eq. 2):

$$P(x \leq x_{add}) = F(x_{add}) \tag{2}$$

Thus, in the stochastic formulation of the problem, there is always a certain probability of exceeding the maximum permissible value x_{add}, which will be determined by the equation (Eq. 3):

$$P_{add}P(x > x_{add}) = 1 - P(x \leq x_{add}) = 1 - F(x_{add}) \tag{3}$$

The value P_{add} is equal to the area of the region of the probability density function $f(x)$ (Eq. 4):

$$P_{add} = \int_{x_{add}}^{\infty} f(x)dx = 1 - \int_{-\infty}^{x_{add}} f(x)dx \tag{4}$$

Acceptable excess probability P_{add} of acceptable criterion value x_{add} – is a subject of a separate study; for practical reasons, it can be argued that this should be a very small quantity. In general, for an arbitrary distribution law of $=e$ integral $\int_{-\infty}^{x_{add}} f(x)dx$ can be quite a difficult task, because it cannot always be expressed through elementary functions. In some cases, the solution of the problem is possible only approximately by numerical methods.

The calculation of P_{add} for the normal distribution law. The normal distribution law (Gaussian law) plays an extremely important role in probability theory and has special significance among other distribution laws. This distribution law is most often encountered in practice. The main feature that distinguishes the normal law of distribution from others is that it is the limit to which other distribution laws approach. It can be shown that the uncertainties are the sum of a sufficiently large number of independent random variables (uncertainties). The normal distribution law is characterized by a probability density of the form (Eq. 5):

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-m)^2}{2\sigma^2}} \quad (5)$$

where $m = M[x]$ – expectation value x; $\sigma^2 = D[x]$ – its variance. The distribution curve according to the normal law has a symmetrical hill-like form. The maximum ordinate of the curve, equal to $\frac{1}{\sqrt{2\pi\sigma}}$, corresponds to the point $x = m$; with distance from point m, the distribution density decreases, and at $x \to \pm\infty$ the curve asymptotically approaches the abscissa. The distribution function of the quantity with the normal distribution law has the form (Eq. 6):

$$F(x) = \int_{-\infty}^{x} f(x)dx = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x} e^{-\frac{(x-m)^2}{2\sigma^2}} dx \quad (6)$$

Random value of x cell has a standard normal distribution if $m = M[x] = 0$ and $\sigma = \sqrt{D[x]} = 1$. In this case, the density and distribution function of the standard normal distribution have the form (Eqs. 7-8):

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \quad (7)$$

$$F(x) = \Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{x^2}{2}} dx \quad (8)$$

Equation (8) is called the Laplace function. Distribution function of normally distributed quantity x and arbitrary values m and σ are expressed through the Laplace function as (Eq. 9):

$$F(x) = \Phi(x) = \Phi\left(\frac{x-m}{\sigma}\right) \quad (9)$$

Random value $h = \frac{x-m}{\sigma}$ is called a standardized or normalized random variable; it has a standard normal distribution. Back to the equation (4), considering $x_0 = M[x] = m$ as the mean of a random value of depletion x with normal distribution law and dispersion σ^2, find the probability of exceeding the permissible value x_{add} of safety criteria (Eq. 10):

$$P_{add} = 1 - \int_{-\infty}^{x_{add}} f(x)dx = 1 - \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x_{add}} e^{-\frac{(x-x_0)^2}{2\sigma^2}} dx \quad (10)$$

Therefore, the probability of exceeding the allowable value of the criterion is calculated as a function of the normalized random variable (Eq. 11):

$$h = \frac{x_{add}-x_0}{\sigma} : \frac{x_{add}-x_0}{\sigma} \quad (11)$$

The calculation of P_{add} for the lognormal distribution law. The lognormal distribution is in many ways more accurate than normal, describes most random variables in nature and technology, especially for those objects whose failure occurs due to wear or fatigue. If the value lnx has a normal distribution with the expected value m and variety σ, then the value x considered logarithmically normally distributed if described by the following probability density function (Eq. 12):

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma x} e^{-\frac{(lnx-m)^2}{2\sigma^2}} \tag{12}$$

The distribution function for the lognormal law has the form (Eq. 13):

$$F(x) = \int_{-\infty}^{x} f(x)dx = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{x} \frac{1}{z} e^{-\frac{(lnx-m)^2}{2\sigma^2}} dx \tag{13}$$

and is not expressed through elementary functions. Numerical characteristics of a value distributed according to the lognormal law:

1) expected value (Eq. 14):

$$M[x] = e^{m+\frac{\sigma^2}{2}} \tag{14}$$

2) variance (Eq. 15):

$$D[x] = \left(e^{\sigma^2} - 1\right)e^{2m+\sigma^2} \tag{15}$$

Assume X is random variable distributed according to the lognormal law with parameters m, σ and cell distribution function $L(x, m, \sigma)$. Then, in accordance with the definition of the lognormal distribution law, the random variable (Eq. 16):

$$Y = ln(X) \tag{16}$$

will be distributed normally with mathematical expectation (Eq. 17):

$$\mu = ln(m) \tag{17}$$

and variance σ. Therefore (Eq. 18):

$$L(x, m, \sigma) = N\left(\frac{lnx-m}{\sigma}\right) \tag{18}$$

where $N(x, 0,1) = \Phi(x)$ is standard normal distribution, which is expressed through the Laplace function (8). Therefore, to obtain the value of the distribution function for the lognormal distribution, it is enough to calculate the values of the distribution function for the standard normal distribution.

The probability of exceeding the allowable value of the criterion x_{add} is defined by equation (3) for the lognormal distribution law, will be written as (Eq. 19):

$$P_{add} = P(x > x_{add}) = 1\Pi P(x \leq x_{add}) = 1 - F(x_{add}) = 1 - \Phi\left(\frac{lnx_{add}-\mu}{\sigma}\right) \tag{19}$$

Probability comparison P_{add} under various distribution laws. Comparison of probability is of interest for further practical use. P_{add} exceeding the criterion x_{add} under various distribution laws, with the help of which the uncertainty in the value of the safety indicator is modeled. In this case, the equivalence of mathematical expectation and variance in each of the distributions is assumed (Table 1).

Table 1. Distribution parameters.

Distribution law	**Distribution parameters**	**Formulas for calculating parameters** $f(x_0, s_0)$
1. Normal: $f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-m)^2}{2\sigma^2}}$	m – mathematical distribution	$m = x_0$
	σ^2 – distribution	$\sigma^2 = s_0^2$
2. Lognormal: $f(x) = \frac{1}{\sqrt{2\pi}\sigma x} e^{-\frac{(lnx-m)^2}{2\sigma^2}}$	m – scale parameter	$m = ln\frac{x_0}{\sqrt{\frac{s_0^2}{x_0^2}+1}}$
	σ^2 – form parameter	$\sigma^2 = ln\left(\frac{s_0^2}{x_0^2}+1\right)$
3. Uniform: $f(x) = \begin{cases} 0, x \notin [a,b], \\ \frac{1}{b-a}, x \in [a,b] \end{cases}$	a – left border	$a = x_0 - \sqrt{3}s_0$
	b – right border	$b = x_0 + \sqrt{3}s_0$
4. Exponential: $f(x) = \lambda e^{-\lambda x}$	λ – distribution parameter	$\lambda = \frac{1}{x_0}$
5. Gamma distribution: $f(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}$	α – form parameter	$\alpha = \frac{x_0^2}{c_0^2}$
	β – scale parameter	$\beta = \frac{c_0^2}{x_0^2}$

The results obtained illustrate the dependence on the adopted distribution law with equal initial data. Distribution law (Eq. 20):

$$P_{add} = f(x_0 = 3, s_0 = 1, x_{add} = 4) \quad (20)$$

Normal – 0.1586553; lognormal – 0.1471852; uniform – 0.2113249; exponential – 0.2635971; gamma distribution – 0.1550278. Rationing of admissible probability P_{add} exceeding safety criteria. Overall limit value P_{add} can be determined by expert judgment as a small given probability. When normalizing values P_{add} we can focus on the quantile (or percentile) of the normal distribution law $F(x_\alpha) = \alpha$. Of particular interest are the quantiles corresponding to points on $x_0 + \sigma, x_0 + 2, x_o + 3\sigma$, and also $\alpha = F(x_{0,95}) = 0{,}95$. We can build a scale of standardization of the value P_{add} (Table 2).

Table 2. P_{add} value normalization scale.

Requirements level for P_{add}	**Quantile** α, %	**Value** x_α	P_{add}
Low requirements	$\alpha < 84{,}14$	$x_0 + \sigma$	$> 0{,}16$

Medium requirements	$84{,}14 < \alpha \leq 97{,}72$	$x_0 + 2\sigma$	0,023…0,16
High requirments	$97{,}72\% < \alpha < 99{,}99$	$x_0 + 3\sigma$	0,001…0,023
Above high requirments	$\alpha > 99{,}99$	$x_0 + 4\sigma$	$< 0{,}001$

Using the SAPHIRE code, the uncertainty of the calculated values is usually simulated with the percentiles calculating 5% and 95% ($P_{add} = 0{,}05$), which corresponds to the standard requirement level in Table 2. The analysis method and its modification are the method of pairwise comparisons, used as the basic one. To establish the relative importance of the elements of the hierarchy (criteria for evaluating alternative solutions), a scale of relations (degree of significance of actions) was used, which allows the expert to set a certain number according to the degree of preference of one object over another. The criteria for nuclear and radiation safety are of absolute importance compared to other criteria (significance level 9). An algorithm for constructing a super criterion has been developed, providing for the following steps:

Step 1. The construction of many matrices of pairwise comparisons. Filling in square matrices of pairwise comparisons is carried out according to the following rule. If the item E_1 is dominating item E_2, then the matrix cell that matches the row E_1 and column E_2, is filled with an integer, and the cell that matches E_2 and E_1, gets filled with the number inverse to it (Eq. 21):

$$\mu = \begin{pmatrix} \frac{\mu_1}{\mu_1} & \frac{\mu_1}{\mu_2} & \cdots & \frac{\mu_1}{\mu_n} \\ \frac{\mu_2}{\mu_1} & \frac{\mu_2}{\mu_2} & \cdots & \frac{\mu_2}{\mu_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\mu_n}{\mu_1} & \frac{\mu_n}{\mu_2} & \cdots & \frac{\mu_n}{\mu_n} \end{pmatrix} \quad (21)$$

To get each matrix, the expert renders $n(n-1)/2$ judgments (where n – is the pairwise comparisons matrix order).

Step 2. Calculation of the maximum eigenvalue of the resulting matrix and the corresponding eigenvector. Eigenvector calculations W of positive square matrix A is performed on the basis of equality (Eq. 22)

$$AW = \lambda_{max} W \quad (22)$$

where λ_{max} – maximum matrix eigenvalue A.

For a positive square matrix A eigenvector W, corresponding to the maximum eigenvalue λ_{max}, up to a constant factor C, can be calculated by the formula (Eq. 23):

$$\lim_{k\to\infty} \frac{A^k}{e^T A^k e} = CW \quad (23)$$

where $e = (1,1,\ldots,1)^T$ – unit vector; k – exponent.

In practice, the calculations of the eigenvector are performed to achieve the specified accuracy ξ: $e^T|W^k - W^{k-1}| \leq \xi$. With sufficient accuracy for practice, we can accept $\xi = 0{,}01$ regardless of matrix order. The maximum eigenvalue is calculated by the formula (Eq. 24):

$$\lambda_{max} = e^T AW \quad (24)$$

Step 3. Calculation of the homogeneity index and homogeneity ratio. The valid value is $BO \leq 0{,}1$. If for the matrix of pairwise comparisons the homogeneity ratio $BO > 0{,}1$, then this indicates a significant violation of the logic of judgments made by the expert when filling out the matrix, therefore, the expert is invited to review the data used to construct the matrix in order to improve uniformity.

Step 4. Construction of the criteria priority vector using the normalization of the eigenvector.

Step 5. Determination of weight coefficients for individual criteria and construction of a supercriterion. At the input, to make a decision on choosing the optimal alternative, we have (Eq. 25):

$$U(a) = \sum_{k=1}^{n\Sigma} \beta_k u_k(a) \to max \quad (25)$$

where β_k – weights obtained using the hierarchy method, a – alternative; $u_k(a)$ – random variable characterizing the value of the criterion k, $u_k(a) \sim N(\mu_k, \sigma_k^2)$.

To evaluate the alternatives, the Hodge-Lehman test was modified to be based simultaneously on the minimax Wald criterion and the Bayes-Laplace criterion. The utility function of the alternatives is defined as (Eq. 26):

$$HL(a) = \alpha E \sum_{k=1}^{n} \beta_k u_k(a) + (1+\alpha) \sum_{k=1}^{n} \beta_k [\mu_k - 3\sigma_k] \quad (26)$$

where $E\sum_{k=1}^{n}\beta_k u_k(a)$ – expected supercriterion value; $\sum_{k=1}^{n}\beta_k[\mu_k - 3\sigma_k]$ – guaranteed result; α – parameter that expresses the degree of confidence in the probability distribution used. If the trust is high, then the Bayes-Laplace criterion is accepted, otherwise the guaranteed result is preferred. The decision is made on condition (Eq. 27):

$$a^* = argmax_a HL(a) \quad (27)$$

Therefore, the basic principles of making risk information decisions and the method of accounting for uncertainties when making risk information decisions are presented.

CONCLUSION

The basic principles of risk information decision making are developed, which is a combination of deterministic and probabilistic methods. It should be noted that the assessment of uncertainties is an integral part of the process of making risk information decisions at the stage of verifying compliance with established requirements and safety criteria and, in fact, when making a risk informed decision. A detailed concept has been developed, which is the main tool for the practical use of established requirements and safety criteria.

The basic principles, stages and criteria for making risk-information decisions that can be implemented in a regulatory document are formulated. To develop regulatory requirements, a method for accounting for uncertainties has been developed, consisting of two structural blocks: accounting for uncertainties when checking compliance with regulatory safety criteria; choosing the right solution from a variety of alternatives for a set of criteria.

To select the appropriate solution from many alternatives for a set of criteria, the method of pairwise comparisons is used. In order to establish the relative importance of the elements of the hierarchy, a scale of relations is applied, which allows the expert to set a certain number according to the degree of preference of one object over another. The criteria for nuclear and radiation safety were endowed with absolute significance in comparison with other criteria. An algorithm for constructing a super criterion is developed. To evaluate the alternatives, the Hodge-Lehman test was modified, which is based simultaneously on the minimax Wald criterion and the Bayes-Laplace criterion.

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