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NPP as a technically complex facility. Global reliability management using “Between True and False” method

The presented research article gives an overview of modern aspects of the concept of reliability and risk management of technically complex construction objects using the example of a nuclear power plant (NPP). Through the analysis of domestic and foreign approaches to the study of NPP reliability management systems, the paper defines the vector of development of applied science in the field of project reliability assessment. The author outlines the problems of development of an integrated system of organizational and economic reliability management of the main stages of construction of nuclear power facilities. The article presents the main theses and description of the author's development of the methodology of reliability assessment of the technically complex NPP system on the basis of multi-criteria approach. It is proposed to use stochastic and deterministic methods of reliability assessment for the technically complex NPP system. The relevance of applying the theory of fuzzy sets is substantiated in the context of the analyzed problem when assessing the degree of reliability of the nuclear power plant as a technically complex real estate property. The method of network graphs construction, forming the basis of the applied software of the organizations performing the functions of customer and contractor of NPP construction, is considered as a sub-base of the system of project reliability assessment by its stages and phases. The article formulates the problems of reliability and risk management, draws conclusions and recommendations on the prospects of NPP reliability management systems development, and identifies directions of further research in this field. It is proposed to create a global map-scheme of the international market of nuclear industry facilities based on their reliability data. The paper substantiates the fact that the creation of such a map will make it possible to inform humankind publicly about the state of energy facilities using peaceful nuclear technology.

Keywords: nuclear power plant (NPP), NPP construction, NPP reliability management, construction risk management, construction economics, industrial construction, multi-criteria reliability assessment, fuzzy set theory in reliability assessment, enterprise economics, mathematical modeling

INTRODUCTION

Within the context of principles, generally recognized by the world community, on the need to enhance international cooperation in the field of nuclear energy and the development of sales markets with a steady growth in demand for nuclear energy, including energy produced using Russian technologies, the issues of safety and reliability of project management in the field of peaceful atom nuclear technology are the most urgent ones that require extensive research. The International Nuclear and Radiological Event Scale, adopted by the IAEA and consisting of seven levels, makes it possible to measure the degree of danger of accidents and incidents that have already occurred. At the same time, it is necessary both retrospectively and prospectively to analyze, evaluate and form safety margins of the existing NPP facilities to prevent similar events in the future, by ensuring the proper degree of reliability of all systems. The presented research and review article is devoted to organizational and economic reliability work in facilities in question. The methodology and principles of reliability management are investigated and the foundations of our own multi-criteria approach to assessing and managing the reliability of a nuclear power facility are proposed. In addition to assessing the reliability of projects, one of the goals of the presented work is to develop the basis for further creation and international use of an interactive map of the world

with zoning of nuclear power facilities (NPP) by their reliability, which will also help to identify the gradation of zones with most favorable conditions for the development of nuclear power. This map will make it possible to observe in real time the current situation in regions whose population and governments are committed to or, on the contrary, opposed to the development of nuclear power technologies, regions with an increasing terrorist threat, as well as regions of prospective development of “peaceful atom” projects.

As a result of the development of the ideas presented in this research, a multi-criteria research method based on a probabilistic approach to reliability assessment using deep expertise was developed based on the obtained and systematized experience in the economic sector under study.

The concept of reliability is at the intersection of such sciences as mathematics and statistics (probability theory, applied mathematics and control processes, physics and chemistry (in terms of studying external physical and chemical influences on the object under study, as well as physical and chemical processes inside the object being studied), as well as economic science (in terms of methods of economic efficiency) (Fig. 1) [1].

According to Nuclear Reactor Information System as of June 2023, the following current statistics of NPP capacity distribution by world regions is given and illustrated at Fig. 2¹.

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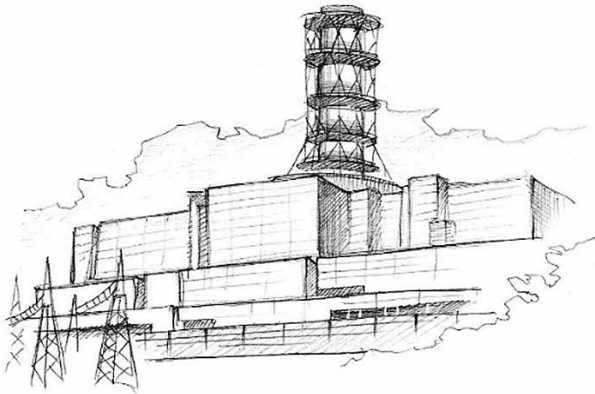


Fig. 1. Sketch to the nuclear plant

This information is of interest for solving the problem of developing and testing a methodology for assessing the organizational and economic reliability of a nuclear power plant project at both the pre-investment and investment stages. In matters of construction of technically complex structures, the basis for the success of the project is location and economic efficiency, determined, among other things, on the basis of the chosen location. The more demanded the project is, the higher its reliability potential due to greater loyalty to the significant costs that:

- must be incurred;
- have guaranteed sources of financing, in addition to subsidy and investment;
- have guaranteed consumption of the project's products, in the case of NPP — this is the supply of electric power and energy to the grid with further distribution to consumer groups [2, 3].

The relevance of the study of project reliability is determined by the fact that in case of lack of reliability or reduction of its threshold in the project, the latter will not be realized. Let us define the concept of organizational and economic reliability. "This is such an economic state of the company, which ensures the effectiveness of its sustainable development, rational use of all types of resources

and satisfaction of all stakeholders within reasonable economic risk" [4].

Initially, let us consider the historical aspect of the scientific development of the concept of reliability. It is accepted to believe that scientific interest was formed in the first half of the twentieth century, when the term "reliability of technical systems" appeared. Later, in the second half of the twentieth and early twenty-first centuries, the concept of economic reliability was formed, following the production reliability [4].

"Modern economic realities of market relations have raised the problem of economic reliability to a new level, ... the indicator of reliability of the organization becomes a key indicator in making managerial decisions; it is given attention by the heads of companies, financial and tax services, government agencies and other organizations that make decisions regarding the position of economic efficiency of the organization's functioning. Absolute reliability of an organization, as well as other systems, is impossible. At the same time, the management of each organization strives for this indicator" [4].

The scientific novelty of the tasks and conclusions presented in the article is due to the fact that many authors of domestic and world science study the theory of economic reliability of the organization; however, the unity in the approach to its definition has not yet been formed.

The author of the presented article sees the future for the development and implementation of the methodology of multi-criteria analysis of system data both at the stage of design and at the stage of construction of a nuclear power plant. Development and implementation of systems of control and management of NPP facility reliability in a unified form is the most important task of the world community, as it becomes obvious that the efficiency of already existing models of control and safety management of high-tech and hazardous facilities has been decreasing. Reducing the influence of the human factor is no longer within the framework of the "four-eyes" method, and "manual" or even "semi-automatic" data collection and input into analytical systems are becoming too politicized and biased, while the world community is making ever-increasing demands to control over the reliability and safety of nuclear facilities. Such integrated systems of management of organizational and economic reliability of the major stages of construction of nuclear power facilities, which can be integrated in a separate system, have

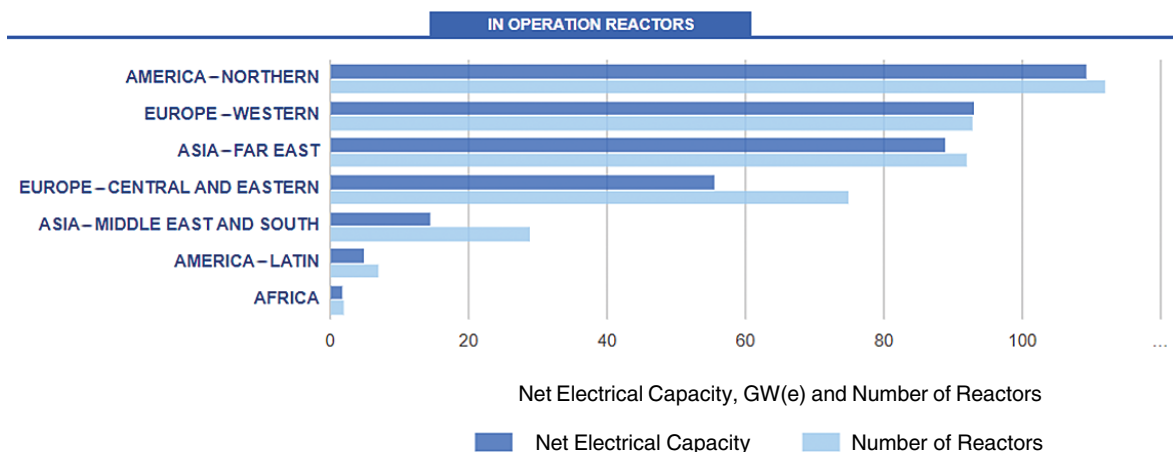


Fig. 2. Regional distribution of nuclear power

not been developed and implemented in the proposed scope. Hence, the article presents the main trends in the development of the nuclear power facilities construction market, as well as the role of ROSATOM in the development of large-scale international projects. In the third decade of the twenty-first century, in addition to the technical reliability of complex structures, the need to develop and improve the methodology for managing the organizational and economic reliability of projects in the nuclear power industry comes to the forefront.

According to the International Atomic Energy Agency, there are currently 438 nuclear reactors in operation worldwide. This figure means that the number of nuclear installations on Earth is more than double than the number of states, and, according to the UN data for 2023, there are 193 of them [5]. Such a scale of coverage of the planet by nuclear technologies makes dedicated specialists consider the reliability of technically complex industrial facilities in the context of organizational and economic problems; first and foremost, how to organize the construction and operation of such facilities reliably and safely [5]. Therefore, the tasks of ensuring the reliability of such systems both at the planning stage (pre-investment stage) and at the stage of implementation and subsequent operation gain crucial importance.

Reliability is “a complex property of systems to perform satisfactorily the required functions within a given time interval, when the probability that the system will perform these functions within a given time interval can be a qualitative characteristic of the property” [6]. **The first method** will be to determine the reliability of the system by means of a number of indicators, the main of which will be the “percentage of implementation” of the economic decision. This indicator will be calculated as follows in the Formula 1 — assessment of reliability of economic decision [6, 7]:

$$H_k = 1 - E = \left(\frac{P_k^0 - P_k}{P_k^0} \right), k = 1, \dots, K, \quad (1)$$

where H_k is assessment of reliability of economic decision by k -indicator of economic solution;

- E is mathematical expectation symbol;
- P_k^0 is projected (planned) value of the k -indicator;
- P_k is its probable actual value;
- K is nomenclature of assessed indicators.

The second method is based on the main property of reliability: inverse dependence on risk. Here reliability becomes the main criterion for evaluating the project being implemented. Thus, mechanisms and levers of reduction, mitigation and compensation of risks of the project system are developed and implemented to manage the reliability of a technically complex system such as an NPP. In this case, the concept of inertia of technological and economic processes is involved, and each of the management decisions taken is specified in the model, after which the researcher can estimate how the inertia (namely, reliability reduction) of the system increases with each subsequent stage. The main stages are planning and organization of work, identification of hazards, risk assessment, and development of risk mitigation recommendations [3].

“Risks cannot be separated from each other. Let us complicate the speculative model by the fact that for such an assessment of organizational and economic reliability of production systems we will allocate stages (periods) according to the principle of stage-by-stage analysis. In our case, the first stage will be the assessment of reliability in the process of preparing a feasibility study (FS) of the project”. This develops the assumption that “a high level of project reliability at the stage of goal-setting significantly increases

the level of reliability of subsequent decisions related to the realization of this project” [3]. The feasibility study of the project, in addition to all technical and economic parameters, contains a clear formulation of the NPP project goal.

Here, the multi-criteria approach to the reliability assessment of NPP projects proposed by the author of the article comes into force. It is possible to supplement the range of analyzed criteria with such criteria as no-risk and optimality, along with the already known criteria of “adaptability, viability, maneuverability, failure-free operation, and stability” [8]. We complicate the model by adding weight and share characteristics, quantitative and qualitative criteria, where the intermediate task of assessing the weight of each criterion is assigned to a specially formed expert council for assessing the reliability of the construction project. The more technically complex and risky the object is, the greater damage can be caused by an error during construction and operation, and the more criteria will be included in the evaluation program. The reliability of the project becomes multilevel and more sustainable.

The proposal of a new multi-criteria approach is also greatly conditioned by the historical aspect. Appealing to the history of the issue development in the domestic science in the sphere of investigating reliability of technically complex systems such as NPPs, it should be noted that a certain vector of studies has been formed. For instance, according to the opinion of scientists who contribute to the development of the concept of technical reliability of enterprises and who publish scientific papers on this subject in “open press available to a wide range of scientific and technical workers” [8], there is an opinion about some insufficiency of materials due to the established view on “absolute safety” of national technologies and equipment, which “until recently was the foundation for prescribing safety standards”. The requirement of “absolute safety, i.e., zero risk, eventually led to costly and even tragic consequences for the country’s population and economy” [8]. Accordingly, “specialists operating technical systems and servicing hazardous technologies in the chemical industry, power systems, and pipeline transport turned out to be methodologically unprepared to search for and analyze critical failures leading to accidents” [8]. Thus, referring to the retrospective aspect of the reliability of technically complex systems, and in contrast to the above opinion, we emphasize the need to include in the assessment of the situation the assumption of a possible sabotage that could have taken place in 1986 [8].

For this reason, **the third method** of reliability research and assessment is proposed: reliability analysis on the basis of systematization of system failures by generic attributes together with grouping and identification of regularities when drawing up schedules for NPP organizational and economic management. The consequence and the result of the wide introduction of this method will be the increase of the level of knowledge about reliability and safety of technically complex industrial facilities up to the level of modern requirements in achieving reliability, in compliance with the current and prospective tasks of engineering development and scientific and technical progress.

The method of possible failure investigation should be applied at the pre-investment stage, at the construction stage, and to an even greater extent at the operation stage. This is dictated by the fact that currently the whole world and Russia as the leading state possessing the so-called dangerous technologies, is moving from dry statistics of accidents to the use of engineering methods of preventive analysis and research of “technical systems and high-risk facilities in order to prevent accidents”. In fact, the world

community is moving from the concept of “react and correct” to the principle of “anticipate and prevent”, including the task of eliminating the global negative effect in the form of disasters and huge economic, social and environmental damage. When working on reliability assessment by the method of investigation of possible failures, such criteria should be added as analysis of the legislative framework of safety of technically complex industrial production, engineering reliability, cyber and information reliability. Here we can use the normative definition of reliability given in GOST standards, where reliability is “the property of an object to preserve, within the established limits, the values of all parameters characterizing the ability to perform the required functions in specified modes and conditions of use, maintenance, repairs, storage and transportation”². This definition characterizes the systems, failures in the operation of which should be critically evaluated when analyzing the reliability of the entire system.

Thus, most methods come down to the fact that reliability should be denoted by a dimensional value. **The fourth method** is the method of probabilistic description of failures depending on the given criteria. Such reliability indicators as failure-free operation, maintainability, durability and safety can be described a) probabilistically, which is more suitable for analytical calculations, and c) statistically, which is used for empirical assessment of the reliability of technical systems. Combining the third and fourth methods, we introduce the concepts of “the time to failure” and “failure probability”. To identify the criteria of NPP system reliability assessment, the concept of mean time to failure is used as a mathematical expectation of the facility operation before the first failure and mean time between failures as a mathematical expectation of the facility operation between failures [8]. Calculation and introduction of indicators into the multi-criteria model will supplement it with a necessary layer of system failure probabilities. The existing systematization of reliability types of NPP systems and equipment, including unit reliability, functional reliability, operational reliability, construction reliability (as strength and durability of building structures), software reliability, and operational reliability will be supplemented by human resource reliability, as further stated in the article. Simultaneously with the assessment of each of the types of reliability given in the systematization, it is necessary to analyze the so-called failures, to identify and assess their causes, which may be the following: the presence of design defects, the presence of errors in the applied technology, the presence of operational errors, temporary failure of a certain system. At the same time, it is necessary to correctly assess the nature of the failure, which can be either instantaneous, or phased, or cumulative, or combined. It is important to understand the nature of failures in order to distinguish between instantaneous and phased failures, as well as stable and quickly ending failures, the latter are called setbacks (in this case the performance of the system is restored immediately and no repair works are needed), in order to further interpret them in the form of probabilistic stochastic models. As the next step, primary and secondary failures are distinguished with the help of statistical probabilistic patterns. By “primary failure of an element” we mean such a failure when the element itself is the cause of the failure. For example, metal fatigue is a primary failure [8]. An equally important role is played by secondary failures when the cause is the current or previous exposure limits affecting the elements of the system, for example, by such energy sources as thermal, mechanical, magnetic, radioactive, thermal, chemical, natural, geothermal, or geological.

Specified factors such as structural factors during design, structural factors during construction, disturbances (deviations) during operation and maintenance of the system, external regular impact including temperature, dirt, moisture, dust, vibration, external emergency effects including fire, flood, earthquake, hurricane, factors of lack of diversification of supply, where the concentration on one manufacturer in case of a system error in the production of units results in the system having a repetitive defective element, seam, equipment, etc. All the above parameters, including assessment of the equipment power supply, both main and backup, operation of measuring devices, planning of protective measures, etc. are all included in the multi-criteria system of NPP facility reliability assessment.

It should be noted that the main task of the organizer and customer of a complex technical system of NPP is to collect empirical statistical data in order to systematize the experience of errors with the subsequent determination of weight criteria for each of them in the input data of the software to identify reliability stress factors of both the project as a whole and its individual subsystems. Let us consider several ways of collecting and analyzing data to assess the reliability of systems. One of the rather simple ways is checklists, as well as “what will happen if...” sheets, i.e. special documents and instructions developed by the engineering and management division of the enterprise. Based on the data collection method discussed above, **the fifth method** of reliability assessment is the development of analytical tables or diagrams of different types: “fault tree”, “decision tree”, “outcome tree”, and “event tree”, which, in its turn, is an advanced version of “decision tree”. The decision tree can be presented in the form of a diagram, which is convenient to apply for NPP operation and is illustrated at Fig. 3 [8].

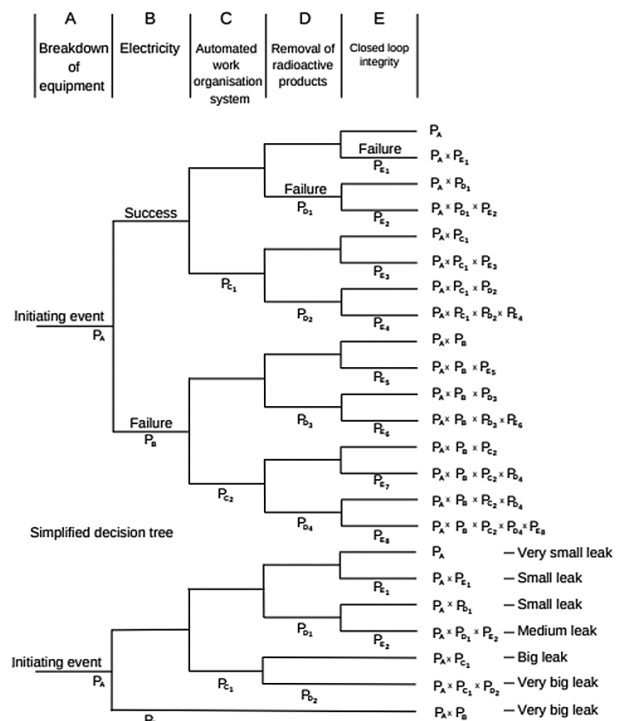


Fig. 3. Illustration of “Decision tree”

In the context of reliability issues of technically complex production facilities the role of the main link — the human resources — cannot be underestimated. The author proposes to adopt the method of human reliability assessment as **the sixth method** of reliability assessment, as the human factor is most important for all technically complex enterprises and production facilities. Reliability assessment with a human factor in mind is relevant both for the investment and design stages of construction, and for the operational and final period. Reliability of human work is measured by the probability of a positive result of this labour, in this case achievement of the task set for a specific period of time is assessed, equal to the stage of the project under certain conditions. Conversely, an error in the work of the project personnel means failure to accomplish the assigned task or a prohibited action or violating the work schedule. It should be taken into account that most of the work at the enterprise is related to human activity, whatever the degree of automation is available.

Human error leads to the failure to fulfill the set goal or, on the contrary, to the performance of a prohibited action, which is the cause of damage to the technical system or violation of the established order of regulated procedures. In the process of operation, most of both automated and non-automated systems require human intervention. Over many years of practice of using both highly skilled and unskilled human labour, it has become obvious that errors are inevitable, and it is impossible to assess reliability without consideration of the results of human participation in the operation of all systems.

Nevertheless, under modern conditions it is not sufficient to assess operator errors from the point of view of the probability of the error itself as an influence of the human factor. There is a relatively new direction in the modern approach of the international scientific community: it involves countering threats from internal violators. This vector, studied and examined at the global level, is under special attention of the IAEA (International Atomic Energy Agency) that developed the relevant Practical Guide in 2008, which will be updated in 2023. The term “operator” or “nuclear operator”, as defined by the IAEA, is used “to designate an entity (person or organization) officially authorized to operate a nuclear or radiological facility or officially authorized to use, store or transport nuclear material and/or radioactive material”. The main condition for the existence of such a risk is the authority, knowledge, and “access that internal actors at the facility may have, including physical access to certain areas and nuclear material, internal or authorized remote access to a computer or computer network, and access to ‘sensitive’ information about the facility”³.

A simple example of countermeasures is the “two-person rule” (or four-eyes method, in the language of programmers), meaning a control method used to achieve a high level of reliability and security of sensitive facilities in the field under consideration, whereby access and actions require two or more authorized persons to be present at all times (as an example, start-up of an installation while using two different keys at the same time). The following measures can be useful: unannounced and unscheduled inspections of the implementation of protective measures, development and implementation of instructions, regular application of administrative penalties, confidentiality and secrecy rules, inspections, including

those involving independent groups, changes in the organizational structure by restricting access, changing the amount of available information (transfer to another area).

Drawing conclusions on the basis for the development of a multi-criteria system for assessing the reliability of a technically complex NPP construction facility, it is recommended to assess the entire set of factors of the organizational and technical process, such as labour resources, including their sufficiency, qualification, loyalty to the enterprise, material and non-material motivation; licensing and legal resources, including compliance of available and mobilized resources with the stated objectives in terms of time, scope and quality; as well as material and technical resources, including production and technical resources, and other resources that affect the safety and risks associated with complex technical production processes.

The development of independent multi-criteria approach is dictated not only by domestic, but also by Western developments, including the “Swiss Cheese Model” introduced by James T. Reason in 1990, which, in the context of the researched problems, the author of the article proposes to apply for the analysis of “cumulative consequences of actions” when assessing the technical, organizational and economic reliability of complex production systems, such as NPP. The analytical model should be supplemented by four types of errors that can lead to so-called project failures that, in turn, arise due to one or more of these errors, namely: management errors (as an example, as a result of the crisis, the reduction in training and professional development costs that subsequently led to the accident); insufficient managerial control at all levels; prerequisites for unsafe actions (for example, placing on the NPP dashboard a “destroy everything” button next to the public announcement button); and unsafe actions themselves⁴.

As the conclusion of the development of a multi-criteria system of NPP reliability assessment, various criteria become the prism of design analysis at each of the following stages of NPP construction:

1. Negotiation stage — preparation for an intergovernmental decision.
2. Preliminary feasibility study.
3. Decision-making at the level of state governments, signing of the intergovernmental agreement.
4. Establishment of a joint working group and updating of the feasibility study.
5. Identification of sources of financing.
6. Site assessment and selection, survey work.
7. Design development.
8. Construction of the facility, including supply of materials, complex equipment, organization of works.
9. Pre-commissioning, commissioning and adjustment works.
10. Lifetime of operation.
11. Decommissioning⁵.

It should be noted that stages from 1 to 7 can be referred to the preparatory stage of the construction project, stages 8 and 9 to the main stage of the construction project, and stages 10 and 11 to the operational stage of the construction project. Each stage should have its own scheduling in order to predict the proper level of reliability of each stage. The stages of NPP construction project realization according to the Built-Own-Operate (BOO) model are described in detail in the report and presentation by Denis E. Sezyomin, devoted

3 IAEA, Regulation on preventive and protective measures to counter threats posed by an insider. 2020. URL: https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1858_web.pdf

4 Reason J. The contribution of latent human failures to the breakdown of complex systems. *Philosophical Transactions of the Royal Society*. 1990; 327(121):475-484. DOI: 10.1098/rstb.1990.0090URL:<https://royalsocietypublishing.org/doi/10.1098/rstb.1990.0090>

5 Alshraideh M., Engovatov I., Morozenko A. Issues of NPP life cycle management. *Energy Policy*. 01.24.2023. URL: <https://energypolicy.ru/voprosy-upravleniyazhiznennym-cziklom-aes/energetika/2023/19/24/#:~:text=Жизненный%20цикл%20АЭС%20последовательно%20включает,начале%20и%20завершении%20указанной%20деятельности>

▶ to the integrated development of undeveloped territories and the experience of “Akkuyu” NPP construction by SC “Rosatom” in Turkey [9]. The results of achieving the design reliability of the NPP construction facility can be illustrated by the creation of a special protective containment resistant to all types of external impacts and their combinations, namely: seismic resistance up to 9 points on the MSK-64 scale, external explosions with a frontal pressure of 30 kilopascals, the fall of an airplane weighing 400 tons at a velocity of 200 m/sec. Fig. 4 shows a general visualization of the containment structure.

In the process of preparing and analyzing the construction schedule, the decommissioning stage is often neglected, which is not quite right, since history knows such examples, in particular, the example of the Berlin NPP, designed, built and excluded from the list of nuclear facilities due to sharp public criticism of the project (1985–1986, coinciding with the Chernobyl accident). The Berlin project underwent radical changes and turned into an amusement park (there is an attraction in the center of the main tower of the NPP, see the Fig. 5). This is not accidental, since from the point of view of reliability in the world practice of creating a nuclear facility, the undermining of confidence in the reliability of NPPs in the global sense led to the rejection of the commissioning and implementation stage of the project, making the project 100 % economically ineffective due to its unreliability⁶. As a result, the investments did not have the planned effect, what is illustrated at well-known panorama at Fig. 5.

When developing the new multi-criteria system, it is important to take into account the domestic experience of studying and using the concept of reliability of NPP project planning, included in Rosatom Order No. 1/1001-P dated 20.09.2013 “On approval of the list of software products for calendar-network planning at the facilities of the Federal Targeted Investment Program”. In order to unify work on schedules, the Order approved the unified use of the Primavera software, with the help of which the relevant schedules are generated. A distinctive feature of the schedules in this software is the division

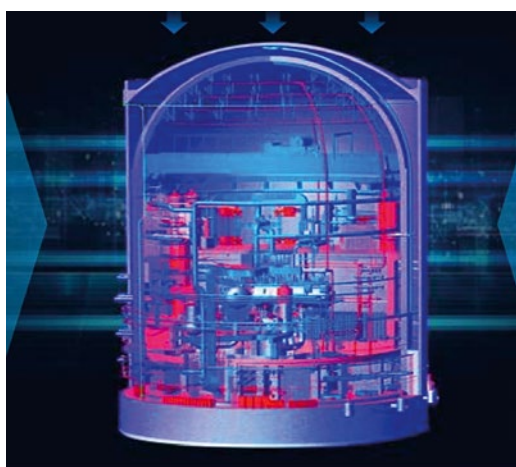


Fig. 4. The containment structure is resistant to all types of external influences and their combinations [9]



Fig. 5. Berliner unrealized NPP⁷

into “top-level schedules that determine the duration of stages and major events of the investment project, the planned date of project completion, a general detailed schedule that provides comprehensive planning of the timing of work (DD, SW, construction and installation, supplies), costs, physical quantities, and detailed schedules of project implementation, which provide management at the level of design, delivery, construction and installation works, commissioning”^{8,9} [10].

The application of fuzzy set theory becomes is a new approach in the practice of developing a set of mathematical multi-criteria models of complex assessment of organizational and economic reliability of the construction of nuclear power facilities. Comprehensive assessment of organizational and economic reliability of the NPP system construction is based on a combination of knowledge and skills of the Customer (society as a whole and public institutions performing functions of the Customer) and the Contractor (in a broad sense, with inclusion of subcontractors, engineers, operational services, etc.); it is also recommended to apply the norms of international law in the field of technical regulation of activities for the creation of technically complex industrial facilities.

Network planning methods based on Gantt charts¹⁰ allow planning compensation measures on the basis of system reliability assessment. They are based on either deterministic network models, where the sequence and duration of works are unambiguously specified or **probabilistic** (or stochastic) **network methods** (models) [11]. In the former methods, an increase in the actual duration of critical works due to certain reasons leads to a corresponding increase in the total duration of the project, while non-critical works have some time reserve.

Because of the dynamic nature of construction and a huge number of factors affecting the success of works, the actual duration and cost of works can only rarely coincide with the parameters set in a deterministic schedule. In the case of technically complex projects aimed at construction of unique buildings using new technologies, it becomes almost impossible to unambiguously identify the duration of works and their interrelation. All this applies not only to the planning of construction works, but also to the planning of other stages of a construction project: development of design and

6 Small Modular Reactors — Was ist von den neuen Reaktorkonzepten zu erwarten? URL: https://www.base.bund.de/DE/themen/kt/kta-deutschland/neue_reaktoren/neue-reaktoren_node.html

7 Wunderland (picture 1). Team Park Project. URL: <https://www.teamparkproject.com/en/projects/wunderland/>

8 Capital construction project management system of the State Corporation Rosatom E70707478. P. 4. URL: atomsro.ru

9 On approval of the list of software products for the implementation of calendar-network planning at the objects of the federal targeted investment program... : Order of the State Corporation Rosatom dated 20.09.2013 No. 1/1001-P.

10 Free Online Gantt Chart Software. No Signup and No Download Required. 100 % Free Forever. URL: <https://www.onlinegantt.com/#/gantt>

estimate documentation, preparation of construction works, etc. The use of stochastic methods leads, on the one hand, to more complicated calculations, but the results obtained are more adequate to real conditions [11].

The application of the project efficiency indicator through net present value (NPV) allows planning quite real probabilistic network models. This method clearly shows that in certain cases when using deterministic models, the project becomes unprofitable and has a negative economic effect. Since the main indicator of the economic reliability of the project is its profitability, this indicator should be planned using a probabilistic approach. A significant novelty of this approach lies in the use of fuzzy set theory, developed back in 1961 by scientist Lotfi A. Zadeh, a Soviet and later American scientist. Currently, the theory is widely used in the management of industrial enterprises and helps to solve challenges with a large number of evaluation criteria. The essence of the method is to determine the best and worst solution, the area between which is called a fuzzy set of solutions. At present, there are digitized mathematical models for analysis of decisions' probable variants; as a result,

a function is created that takes into account the influence of internal and external factors and it is possible to calculate the outcome of organizational and managerial decisions. "The special value of such models lies in the fact that the subject of the management process has numerical values of the controlled parameters at the output of the system, thus he or she not only sees the results of the controlling influence, but also can determine which of them in these conditions are the most flexible and to establish the degree of their influence on the project, which allows to promptly intervene in the management process, choosing the most effective measures of influence" [12–14].

The theory of fuzzy sets and fuzzy logic [12] can be applied as a modern method of assessing the quality of personnel. This theoretical approach is becoming increasingly relevant due to the need to systematize and formalize uncertain information for the creation of mathematical models. In mathematical science, the concept of fuzzy sets is introduced as "the function of belonging of an arbitrary element from a universal set to a fuzzy set", what is well illustrated in modern science and formed in following Table [12–14].

Basic concepts of the theory of fuzzy sets and fuzzy logic [12, 13]

Category	Content
Fuzzy set	A set of pairs where elements have different grades of membership to the fuzzy set
Membership function	Degree of belonging of an arbitrary element of the universal set to fuzzy set $A[0, 1]$
Fuzzy variable	Set $\langle \alpha, X, A(\alpha) \rangle$, where α is the name of the variable; X is the domain of definition of fuzzy variable α (basic, universal set); $A(\alpha) = \{ \mu_\alpha(x) / x \in X \}$ is a fuzzy subset of set X describing the constraints on the possible values of the variable
Variable	Set $\langle \beta, T(\beta), X, G, M \rangle$, where β is the name of the variable; $T(\beta)$ is a set of values of variable β (term-set); X is a universal set (definition domain of β); G means general rules, often in the quality or quantity, generating the name of factor; M is the rules specifying the membership functions of fuzzy terms generated by general rules
Fuzzy knowledge base	A set of fuzzy production rules $PR = \{ pr_1, pr_2, \dots, pr_s \}$ of the "if-then" types in deterministic form
Fuzzy logic inference	The general logical scheme of logical inference includes: <ul style="list-style-type: none"> • fuzzification; • implication; • composition; • defuzzification

CONCLUSION

The article presents an analytical review of methods for assessing the reliability of technically complex projects of NPP construction, systematization of which helps the author to develop an updated methodological multi-criteria approach to assessing the organizational and economic reliability of a production system. The new multi-criteria methodology assesses reliability both at the pre-investment and investment phases of construction of a technically complex industrial facility, such as construction of a nuclear power plant in any state and jurisdiction. The author uses a globalized approach, applying Russian and international experience of addressing reliability problems. The main idea is to develop a unified approach to such an assessment and make the information more open through an interactive map of the global international space with regional zoning of peaceful nuclear technology uses [15, 16].

One of the main directions of research conducted by the author of this work is the development and systematization of methodology recommendations for the selection of a rational option of the plan of work organization on the basis of a simulation model with the use of

modern automated systems of calendar planning. The main research goal of the author for the medium term is the development of a strategy to improve the organizational and economic reliability of the designed construction and technical solutions under risk conditions at the preparatory and main stages of construction of large industrial facilities with the example of high-capacity nuclear power plants.

The author sees further research of the presented topic in the area of development of the state-of-the-art automated system of technical process and reliability management. It is proposed that this automated system should be based on the feasibility study of the project, including data on the design capacity of the plant with indication of the required number of power units, in the composition of which it is necessary to design a certain number of reactors, select the construction area and assess the volume and return on investment, profitability and payback of the construction project. Such a cybernetic model will allow calculation of the economic result of the strategy for each period of the project development [17–19].

The study of issues related to organizational and economic reliability of complex industrial facilities and production systems is one of the leading directions of economic development of the countries all

over the world regardless of climatic, geographical and political features of countries and economies. The multi-criteria approach outlined by the author is applicable to assessing the reliability of technically complex industrial facilities not only in the nuclear industry, but also in other technically challenging sectors of the economy that affect a large number of people, such as the aerospace industry and public healthcare.

REFERENCES

1. Can Sodium Save Nuclear Power? *Scientific American*. Retrieved 24.11.2021. URL: <https://www.scientificamerican.com/article/can-sodium-save-nuclear-power/>
2. Mamdani E. Fuzzy inference system. 1975.
3. Kabanov V. Economic reliability of the company. *Management*. 2007; 10. (rus).
4. Andreeva G.S. Economic reliability of the organization: approaches to the definition. *Young scientist*. 2016; 18(122):227-230. URL: <https://moluch.ru/archive/122/33687/> (rus).
5. Nuclear power reactors in the world. *International Atomic Energy Agency*. 2015; 2:11. URL: www-pub.iaea.org/MTCD/Publications/PDF/rds2-35web-85937611.pdf
6. Sokolov S.A. Economic reliability in the management of investment and construction activities of a construction company : dissertation of the Candidate of Economic Sciences. Novosibirsk, Siberian Institute of Banking, 2006; 224. (rus).
7. Yudina L.N. Economic reliability and risks. *Bulletin of the South Ural State University. Ser. Economics and Management*. 2016; 10(3):51-53. DOI: 10.14529/em160306 (rus).
8. Kulagin A.V., Shirobokov S.V. Reliability of technical systems and technogenic risk : Educational and methodological manual. Izhevsk, Udmurt University, 2020; 110. (rus).

АЭС как технически сложный объект недвижимости — глобальное управление надежностью по методу «betweentrue&>false»

В представленной обзорной научно-исследовательской статье раскрываются современные аспекты понятия управления надежностью и рисками технически сложных объектов строительства на примере атомной электростанции (АЭС). Через анализ отечественного и зарубежного подходов к исследованию систем управления надежностью АЭС в работе определяется вектор развития прикладной науки в области оценки надежности проектов. Автором излагаются проблемы разработки интегрированной системы управления организационно-экономической надежностью основных фаз строительства объектов атомной энергетики. Содержатся основные тезисы и описание авторской разработки методики оценки надежности технически сложной системы АЭС на основе многокритериального подхода. Предлагается использовать стохастический и детерминированный методы оценки надежности технически сложной системы АЭС. Обосновывается актуальность применения теории нечетких множеств в контексте исследуемой проблематики при оценке степени надежности технически сложного объекта недвижимости — атомной станции. Метод построения сетевых графиков, заложенный в основу прикладного программного обеспечения организаций, выполняющих функции заказчика и исполнителя строительства АЭС, рассматривается как подоснова системы оценки надежности проекта по его этапам и стадиям. В статье формулируется проблематика управления надежностью и рисками, в выводах и рекомендациях обозначаются перспективы развития систем управления надежностью АЭС, определяется направление дальнейших исследований в данной области. Предлагается создание глобальной карты-схемы международного рынка объектов атомной промышленности на основе данных об их надежности. Обосновывается факт, что создание такой карты-схемы сде-

9. Sezemin D.E. Comprehensive development of undeveloped areas. experience of Akkuyu NPP construction by Rosatom State Corporation (Turkey). *Real Estate: Economics, Management*. 2022; 3(A):33-37. URL: <https://n-eu.iasv.ru/index.php/neu/issue/view/20/27> (rus).
10. Bellman R.E., Zadeh L.A. Decision-making in a fuzzy environment. *Management Science*. 1970; 17(4):141-164. URL: <https://www.dca.fee.unicamp.br/~gomide/courses/CT820/artigos/DecisionMakin gFuzzyEnvironmentBellmanZadeh1970.pdf>
11. Bovtееv S.V., Chaika Yu.O. Probabilistic planning of the construction of facilities. *World of Construction and Real Estate*. 2006; 14:52-54. (rus).
12. Isaeva O.V. The tools of fuzzy logic in problems of staff selection. *Modern Economics: Problems and Solutions*. 2017; 85:22-27. URL: <https://journals.vsu.ru/meps/article/view/6063> (rus).
13. Shmaneva L.V. Application of fuzzy set theory for organization management system modeling. *Bulletin of the Moscow University of the Ministry of Internal Affairs*. 2021; 4:267-271. URL: <https://cyberleninka.ru/article/n/primeneniye-teorii-nechetkih-mnozhestv-dlya-mod-elirovaniya-sistemy-upravleniya-organizatsiyami> (rus).
14. Clark W. The Gantt chart, a working tool of management. New York, Ronald Press, 1923; 186.
15. Alshraydekh M., Engovatov I., Morozenko A. The issues of NPP life cycle management. *Energy Policy*. 2023; 1:56-71. DOI: 10.46920/2409-5516.2023_1179.56
16. Japan turns back to nuclear power in post-Fukushima shift. *Financial Times*. 24 August 2022. Retrieved November 15, 2022.
17. Reactors: Modern-Day Alchemy — Argonne's Nuclear Science and Technology Legacy. www.ne.anl.gov. Retrieved 24 March 2021.
18. Small Modular Reactors — Was ist von den neuen Reaktorkonzepten zu erwarten?. *BASE (in German)*. Retrieved 24 November 2021.
19. Reason J. The contribution of latent human failures to the breakdown of complex systems. *Philosophical Transactions of The Royal Society B Biological Sciences*. 1990; 327(1241):475-484. DOI: 10.1098/rstb.1990.0090

лает возможным общедоступно информировать человечество о состоянии объектов энергетической системы, применяющих технологию «мирного атома».

Ключевые слова: атомная электростанция, строительство АЭС, управление надежностью АЭС, управление строительными рисками, экономика строительства, промышленное строительство, многокритериальная оценка надежности, теория нечетких множеств в оценке надежности, экономика предприятия, математическое моделирование

СПИСОК ИСТОЧНИКОВ

1. Can Sodium Save Nuclear Power? *Scientific American*. Retrieved 24.11.2021. URL: <https://www.scientificamerican.com/article/can-sodium-save-nuclear-power/>
2. Mamdani E. Fuzzy inference system. 1975.
3. Кабанов В. Экономическая надежность компании // *Управление компанией*. 2007. № 10.
4. Андреева Г.С. Экономическая надежность организации: подходы к определению // *Молодой ученый*. 2016. № 18 (122). С. 227–230. URL: <https://moluch.ru/archive/122/33687/>
5. Nuclear power reactors in the world. *International Atomic Energy Agency*. 2015. № 2. С. 11. URL: www-pub.iaea.org/MTCD/Publications/PDF/rds2-35web-85937611.pdf
6. Соколов С.А. Экономическая надежность в управлении инвестиционно-строительной деятельностью строительной компании : дисс. ... канд. экон. наук. Новосибирск : Сибирский институт банковского дела, 2006. 224 с.
7. Юдина Л.Н. Экономическая надежность и риски // *Вестник ЮУрГУ. Серия «Экономика и менеджмент»*. 2016. Т. 10. № 3. С. 51–53. DOI: 10.14529/et160306
8. Кулагин А.В., Ширококов С.В. Надежность технических систем и техногенный риск : учебно-методическое пособие. Ижевск : Удмуртский университет, 2020. 110 с.
9. Сезёмин Д.Е. Комплексное развитие незастроенных территорий. Опыт строительства АЭС «Аккую» ГК «Росатом»

(Турция) // *Недвижимость: экономика, управление*. 2022. № 3 (приложение). С. 33–37. URL: <https://n-eu.iasv.ru/index.php/neu/issue/view/20/27> (rus).

10. Bellman R.E., Zadeh L.A. *Decision-making in a fuzzy environment* // *Management Science*. 1970. Vol. 17. Issue 4. Pp. 141–164. URL: <https://www.dca.fee.unicamp.br/~gomide/courses/CT820/artigos/DecisionMakingFuzzyEnvironmentBellmanZadeh1970.pdf>

11. Бовтеев С.В., Чайка Ю.О. Вероятностное планирование строительства объектов // *Мир строительства и недвижимости*. 2006. № 14. С. 52–54.

12. Исаева О.В. Инструментарий нечеткой логики в задачах отбора персонала // *Современная экономика: проблемы и решения*. 2017. № 1 (85). С. 22–27. URL: <https://journals.vsu.ru/meps/article/view/6063>

13. Шманёва Л.В. Применение теории нечетких множеств для моделирования системы управления организациями // *Вестник Московского университета МВД*. 2021. № 4. С. 267–271. URL: <https://cyberleninka.ru/article/n/primeneniye-teorii-nechetkih-mnozhestv-dlya-modelirovaniya-sistemy-upravleniya-organizatsiyami>

14. Кларк У. Графики Ганта: Учет и планирование работы. 5-е изд. / пер. с англ. инж. З. Папернова. М.; Л.: Техника управления, 1931. 124 с.

15. Альшрайдех М., Енговатов И., Морозенко А. Вопросы управления жизненным циклом АЭС // *Энергетическая политика*. 2023. № 1. С. 56–71. DOI: 10.46920/2409-5516.2023.1179.56

16. Japan turns back to nuclear power in post-Fukushima shift. *Financial Times*. 2022. Retrieved 15.11.2022.

17. *Reactors: Modern-day alchemy — Argonne's nuclear science and technology legacy*. Nuclear Engineering Division. Retrieved 24.03.2021. URL: www.ne.anl.gov.

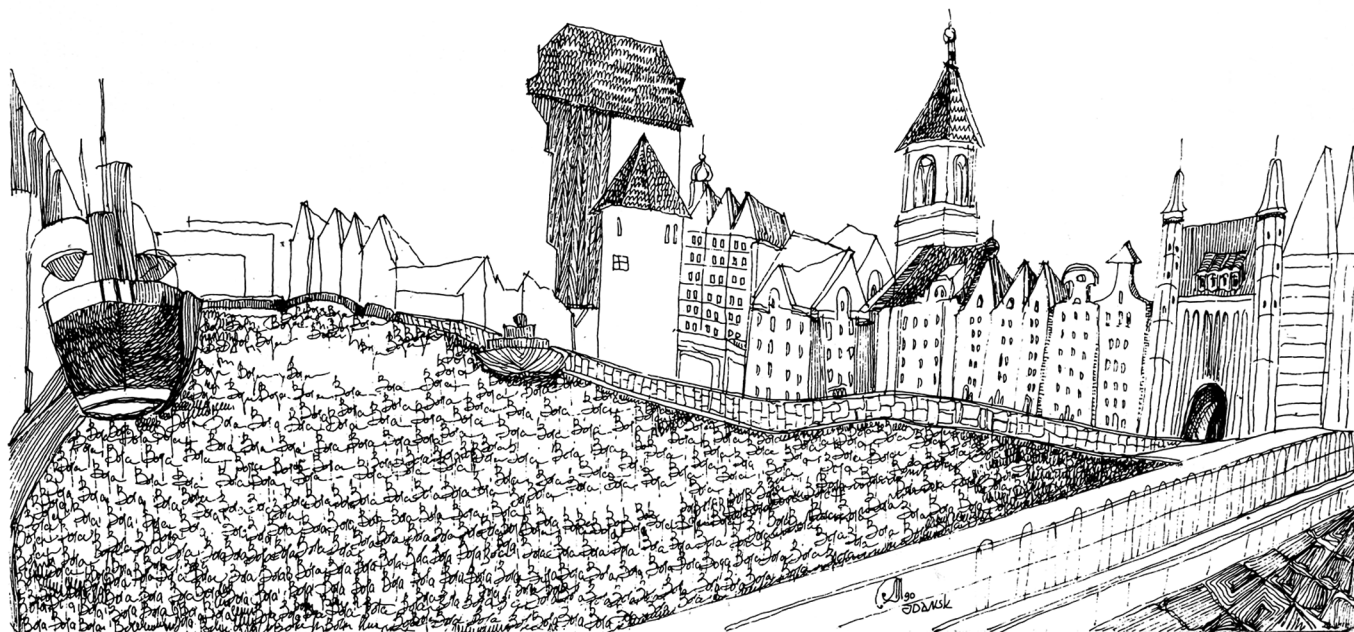
18. *Small Modular Reactors — Was ist von den neuen Reaktorkonzepten zu erwarten?*. BASE (in German). Retrieved 24.11.2021.

19. Reason J. The contribution of latent human failures to the breakdown of complex systems. *Philosophical Transactions of The Royal Society B Biological Sciences*. 1990; 327(1241): 475–484. DOI: 10.1098/rstb.1990.0090

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