

## AGGREGATE RISK OF A LARGE COMPLEX CONSTRUCTION PROJECTS OF NPP

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**Abstract:** The article identifies the problems of the modern international nuclear energy market, analyzes domestic and foreign experience in the construction of technically complex megaprojects, studies and systematizes organizational and technical aspects of the concept of reliability and risks of technically complex industrial facilities on the example of an international project for the construction of a nuclear power plant. The purpose of the research article is to solve one of the most important tasks – to determine the total investment risk and its assessment in an inextricable relationship with the stages of the project life cycle. The article systematizes both the principles of assessing the organizational and technical reliability of the system under study, as well as the methods of types of aggregate investment risk. A proprietary multi-criteria approach to the concept of reliability is being developed using modern theoretical methods in the context of the development of nuclear power plant construction projects abroad, respectively, taking into account country and industry risks.

**Keywords:** nuclear power plant (NPP) construction, organizational and technical reliability management, aggregate risk, mathematical modelling, computer risk modelling, risk management, industrial construction, membrane method

## СОВОКУПНЫЙ РИСК ПРИ РЕАЛИЗАЦИИ КРУПНОГО КОМПЛЕКСНОГО ПРОЕКТА СТРОИТЕЛЬСТВА АТОМНОЙ ЭЛЕКТРОСТАНЦИИ

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**Аннотация:** В статье выявлены проблемы современного международного рынка атомной энергетики, проанализирован отечественный и зарубежный опыт строительства технически сложных мегапроектов, исследованы и систематизированы организационно-технические аспекты концепции надежности и рисков технически сложных промышленных объектов на примере международного проекта строительства атомной электростанции. Целью научной статьи являлось решение одной из важнейших задач - определение совокупного инвестиционного риска и его оценки в неразрывной связи с этапами жизненного цикла проекта. В статье систематизированы как принципы оценки организационно-технической надежности исследуемой системы, так и методы оценки совокупного инвестиционного риска. Разрабатывается проприетарный многокритериальный подход к понятию надежности с использованием современных теоретических методов в контексте развития проектов строительства АЭС за рубежом, соответственно, с учетом международных и отраслевых рисков.

**Ключевые слова:** строительство атомных электростанций (АЭС), управление организационно-технической надежностью, совокупный риск, математическое моделирование, компьютерное моделирование риска, управление риском, промышленное строительство, мембранный метод

### INTRODUCTION

In a broad sense, the developed ACSTP should be based on the feasibility study (feasibility

study of the NPP project), where the capacity of the nuclear plant is specified, the number of power units, the number of reactors as part of the justified feasibility study, the region of con-

struction, the assessment of the volume of investment and calculation of return on investment, project profitability and investment yield. In the ACSTP, the problem of organizational and technical reliability ( $P^a$ ) assessment of NPPs is divided into four levels:

- Field level of technological process;
- Controller level of process control and management;
- Backbone network level;
- Upper level of man-machine equipment, and the area of occurrence of cumulative risks ( $V_{ij}$ ) into three levels (Fig. 1):
  - Organizational and production subsystem
  - Financial-investment subsystem
  - Infrastructure-service subsystem.

As a result of scientific research, the basic principles of cybernetic model of modern Russian ACS for NPP projects have been determined. The stages of development of the method of risk assessment include the following sequence: determination of technical requirements for the control and management system to be designed; development of design and estimate documentation; collection and study of initial data; compilation of a complete list of variables; completion of the ACSTP system (risk assessment); division of the control process into technological sections and subsequent distribution of variables by sections and groups; creation of proprietary databases (project risk map); development of a graphical interface of the screens of operators and management staff alternately in dynamics and statics; drawing up schemes of transitions from static to dynamic images on the screens; drawing up algorithms of scenario control (for all possible modes of operation of the facility, including emergency and post-emergency); creation of a model of the dynamic system of aggregate risk management; verification of databases; development of operational documentation; offline system testing; operational system testing; formal implementation, commissioning, staff training, issuance of relevant orders and instructions.

## MODELS AND METHODS

Figure 1 provides a model of cumulative risk management. A system of continuous risk assessment and control is introduced through the development of the ACSTP model at the feasibility study stage as a strategically planned step simultaneously with the risk management model. It allows to achieve the previously presented main four objectives of the project, such as: timing, cost, quality and safety of the project.

The membrane method of risk assessment is based on the algorithm of calculation of the full economic result of the contractor's risk management strategy for each stage (phase) of the NPP project life cycle. For the purposes of this study, the stages, or layers, of the membrane method of risk management and further the software recommended for development on the basis of the membrane method of risk management, are understood as: initiation, planning, development of criteria and strategy of NPP location (interrelated with stages 3, 4, 5, 6, 9), design (interrelated with stages 1,3–9), construction (interrelated with stage 1), commissioning, operation, extension of operation (modernization), termination of operation, shutdown of processes, decommissioning [6].

Each of the eleven project phases represents a layer of the membrane-based risk assessment system. An example of risk assessment is presented in Tables 1–3.

The three-dimensional representation of the membrane model of assessment of organizational and technical reliability  $Prel(t)$  looks as follows: risks by groups form the membrane layers, which, in turn, form the so-called “membrane pie” by stacking layers on top of each other. The layers are arranged horizontally in the order of the life cycle stages of the project of a technically complex facility – a nuclear power plant.

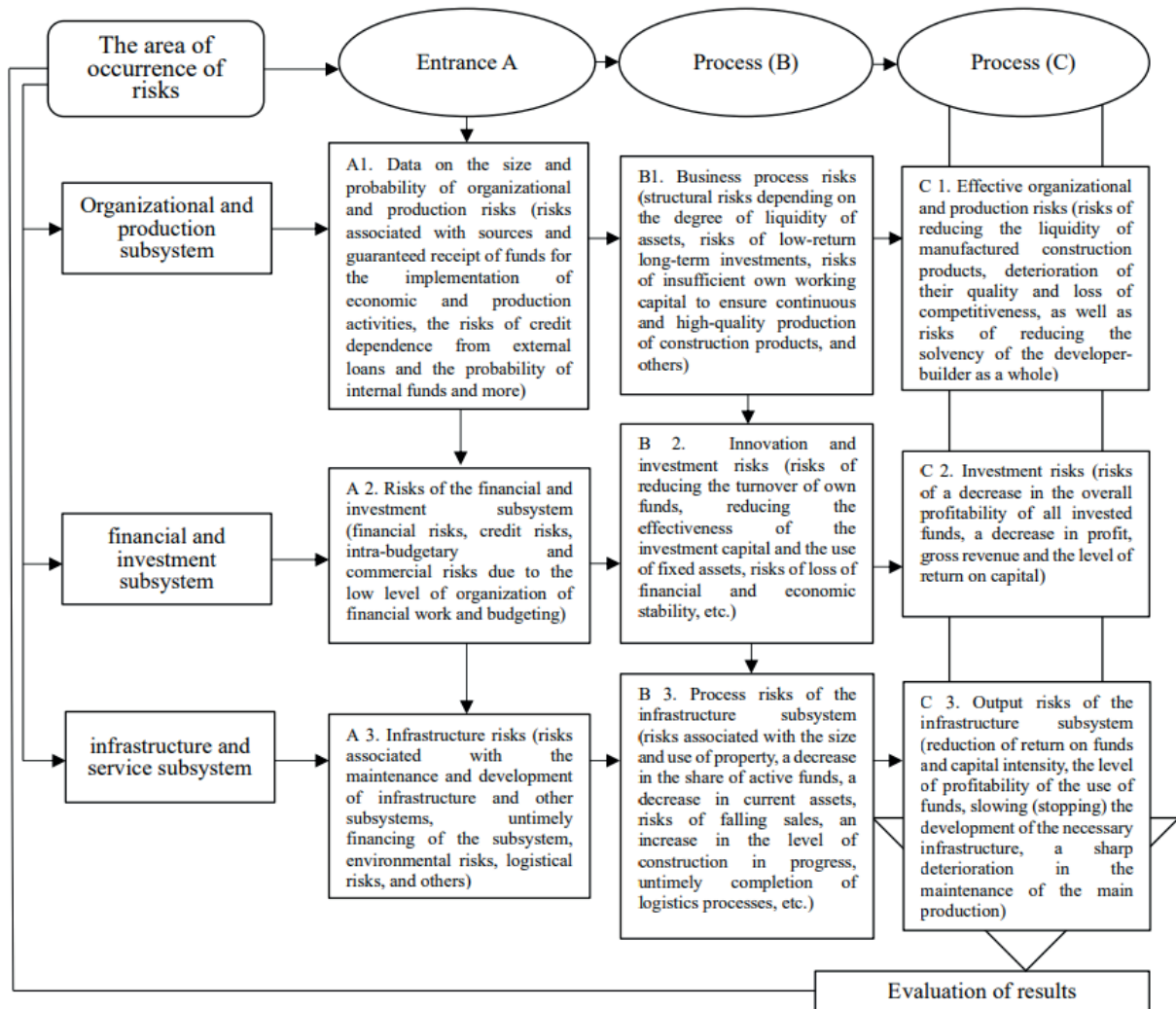


Figure 1. Model of the dynamic system of aggregate risk management at NPPs

The lattice of stacked membranes has several effects: “spring effect,” “impermeability effect” (hereinafter impermeability is understood as the optimal degree of overall project reliability), and “layer–problem–balance” effect. It should be noted that the description of the membrane method through the 3D picture gives an idea of the significance and relevance of the task of systematization and digitalization of big data in the field of assessment and reduction of the maximum possible number of risk types during the

construction of technically and organizationally complex NPP projects. Organizational and technical reliability of NPP project implementation by the developer is a state in which its economic activity ensures, under normal conditions, the fulfilment of all obligations to the public procurement authority (Rosatom State Corporation).

Table 1

**Example of a summary table of cumulative risks**

Risk Category	Name of Risk	Risk Factor	Scenario of Risk	Aftereffect of Risk	Risk Owner	Start and Remanent Risk Level										Previous Index	
						Value of Risk	Probability	Susceptibility	Chart of Project	Cost of Project	Purpose of Project	Influence of project on quality	Influence of project on quantity	Influence of project on security	Influence of project on reputation		
Growth	Mistakes at the projecting stage of project			1. New type of activities. 2. Changes at technical documentation. 3. Growth of cost. 4. Delivery delays.													

Changing risk event	Risk influence horizon	Identifier of Risk	Special code of risk	Name of operations under risk	Duration	Start	Completion	Manageability	Level of manageability	Level of risk remanent										Previous Index	
										Rate of Risk	Probability	Susceptibility	Susceptibility base	Chart of project	Value of project	Purpose of project	Influence of project on quality	Influence of project on quantity	Influence of project on security		Influence of project on reputation

Table 2

Example of a summary table of risk factor impact assessment

Impact on volume	Impact on safety		Impact assessment
Changes in volumes can be covered by current contractual obligations	The assessment of the impact of risks on safety is carried out in accordance with the requirements of current legislation and local regulations. Methods of risk prioritization, scoring scales and significance criteria for environmental safety, industrial safety, occupational safety, information security and other related risks are set in special documents issued under the Project.	The level of decrease in public trust at the local level is insignificant.	1
Additional agreements are required within the existing contractual framework		Decrease in the level of public confidence at the local level. Short recovery period	2
Additional agreements with Contractors required		Decline in public confidence at the regional level. Short/moderate recovery period	3
Additional agreements with the Client required		Decline in public confidence at the international/regional level or at the level of important partners. Moderate/long recovery period	4
Revision of substantial terms of EPC contract/contract with Tier 1 Contractor required		Damage to public trust at international or key partner level. Long recovery period	5

Table 3

Assessment of the impact of risks with background colouring

Probability	Impact assessment				
	1 Very low	2 Low	3 Medium	4 High	5 Very high
5 Very high	5	10	15	20	25
4 High	4	8	12	16	20
3 Medium	3	6	9	12	15
2 Low	2	4	6	8	10

Organizational and technical reliability ( $P_{i-j}^{rel}$ ) affects the production and economic stability, financial and economic performance of the enterprise itself and acts as one of the indicators of risk assessment of the contractor under the state contract (formula 3).

$$P_{i-j}^{rel} = 1 - \frac{\sum_{i=1}^n m_i}{n(n-1)} = 1 - \frac{M(P,H)}{n(n-1)}, \quad (1)$$

Where  $P_{i-j}^{rel}$  is assessment of organizational and technical reliability of the customer;  
 n is the number of indicators in the dynamic reliability model (normative model);  
 m<sub>i</sub> is the number of inversions in the actual order for the indicator having the 1st rank (occupying the first place) in the dynamic model;  
 M (P, H) is the sum of inversions in the actual order of indicators (P) relative to the normative order (H) specified in the dynamic model. Inversion (R) in the presented assessment is expressed by the ratio of the value of M (P, H) relative to n(n-1).

It characterizes the measure of the aggregate risk of deviation of the actual state from the normal state of the customer.

As noted above, the authors' approach proposes to distinguish four main target parameters, which are

affected by risks (groups of risks) and the aggregate risk exposure of the enterprise, namely:

- 1) Project realization timeline;
- 2) Budget of the project realization;
- 3) Quality of the project and its products;
- 4) Project safety.

In this case, we can introduce the following system of registering data on the analysis of risk types, expert assessment of their impact on the target indicator of the project, and the weight of each risk for the indicator "Project Implementation Budget," presented in Tables 4–7.

5) Risk ranking. The assessment is made by evaluating the impact of the relevant risk on the project targets, having previously determined the magnitude of each risk by applying the previously described scoring system – the probability of risk occurrence and the risk exposure of the system.

Table 6 is filled in sequentially from the magnitude of negative consequences of risk types (very low to very high), taking into account their gradient.

6) Identify recommended strategies for the effective impact of risk management activities on project targets.

7) Present the data to the risk expert panel. The results are summarized in a table using the following example (Table 7).

*Table 4*

Risk scale. Layer 1.

Type of budget risk for project implementation	Budget growth in % up to 1%	Budget growth from 1% to 2%	Budget growth from 2% to 3%	Budget growth from 3% to 4%	Budget growth from 4% to 5%	Budget growth from 5% to 6% and so on
Design delay	*					
Delay in construction works						*
Delay in equipment delivery						*
Level 1 human error resulting in accident and equipment failure (by type of equipment)			*			
Changes in average annual air temperature by 1°C				*		
Currency exchange rate fluctuations						*
Strike of transport workers for 10 days or more		*				

*Table 5*

Layer 2

Target indicator		Weight/qualitative indicator				
		Item No	Item No	Item No	Item No	Item No
Budget	Operational costs	Increase by 1%	Increase by 2%	1	2	3
	Capital expenditures					
Schedule		Delayed by 0 month	Delayed by 1–2 months	Delayed by 3–4 months	Delayed by 5–6 months	Delayed by 7–12 months
Quality		No deterioration	Minor impact (on part of project activities), possible adjustment	Requires Client approval	Unacceptable	The project is better not to be implemented in this capacity
Safety	ecological	On the basis of a specially created expert panel, legislative requirements and internal regulations and rules, an appropriate membrane layer of risk impact on project safety is described, taking into account the assessment of costs to ensure the required level of safety. It is included in the terms of reference for the development of software for the risk assessment system using the membrane method.				
	industrial					
	information					
	labour safety					

*Table 6*

Probability	Impact assessment				
	Very low	Low	Medium	High	Very high
Very high	1/5	2/5	3/5	4/5	5/5
High	1/4	2/4	3/4	4/4	5/4
Medium	1/3	2/3	3/3	4/3	5/3
Low	1/2	2/2	3/2	4/2	5/2
Very low	1/1	2/1	3/1	4/1	5/1

*Table 7*

Development of strategies and interventions based on the risk score determination

Risk score (determined by experts)	Strategy	Measures
1–4	Acceptance	Control measures
4–15	Control (reduction)	Compensatory measures, continuous monitoring
15–25	Reduction, rejection	Compensatory measures, continuous monitoring

**RESULTS**

Calculation of acceptable (unmanaged) risk after application of compensating measures is the next stage of the algorithm of work with the risk management system. The calculation is recommended to be carried out in two directions: assessment of the possibility of influence on the probability of occurrence of a risk event and as-

essment of risk on the possibility of application of compensating measures. Here the derived function formula is applied, similar to the risk analysis, when the value of multipliers is reduced by the value of manageability for each type of multiplier. Manageability can also be determined by expert judgment, when each score (on a selected scale) is assigned a degree from 0 to 100.

The final value of residual risk is calculated as arithmetic mean of the normal Gaussian distribution, where the upper and lower values of the studied parameter are not included into the area of analysis.

Simulation models are used for quantitative assessment of aggregate risks; each of them is assigned a rating in the form of a number. The impact of risk types on the project is assessed both for each separately and aggregate risks. After reducing the degree of risk, a second assessment is done, based on the identified trends, and a decision is made on the further implementation of compensatory measures. The Monte Carlo method is used, based on the use of random number sampling. A special algorithm assigns a random event, with the help of which the probabilistic problem is solved. This method replaces complex algebraic computations in the following three cases:

1. when modelling complex operations with interaction of many random factors;
2. when verifying the applicability of analytical methods of research and clarifying the conditions of their applicability; it should be taken into account that the calculations are carried out repeatedly (e.g., 100 times); and
3. when developing corrections to empirically derived analytical formulas [8].

The essence of the developed risk assessment methodology is in the use of the parametric method as an initial (preliminary) method (for systems that do not have well-defined planned costs and realization terms, including for the assessment of projects at the stage of feasibility study). An example of such a risk assessment is the probability of failure of construction of a nuclear power facility at a given location (territory). This is illustrated by the transfer of the construction site of the Turkish NPP to Akkuyu from Sinop province (in 1980, the planned location of the NPP was Injeburun district of Sinop province, and the site in Akkuyu is Gulnar district of Mersin province). In 2017, the Turkish Atomic Energy Agency approved the design parameters of the Akkuyu NPP site.

Based on the results of identifying all possible types of risks and their assessment using the presented methodological approaches, risk registers are developed, both integrated (for the entire project) and localized (by project subdivisions), and experts on a particular type of risk are involved in the finalization of each of the registers.

It is proposed to organize the activity within a single scale from risk acceptance to risk avoidance (exclusion of action) and then divide the risks into groups depending on the degree of riskiness of action:

1. Acceptable risks are those that can be accepted at a given stage of the project life cycle; it should be noted that risks at different stages of the project life cycle are also distinguished by the degree and the actions that need to be taken to bring the risk to an acceptable level.
2. Risks that should be reduced are those whose management reduces the likelihood of an event. Staff training is a prime example.
3. Risks that should be increased are those leading to positive effects for the project.
4. Planned risks are risks for which it is possible and acceptable to develop and implement an action plan to reduce risk to acceptable levels.
5. Transferable risks, for which the best solution is to transfer them on a contractual basis under certain guarantees and responsibility of the contractor.
6. Avoidable risks are those that result in the avoidance of a given action or such a significant change in the operation of the system that eliminates the risk.

In this regard, the authors identify five main degrees of the customer's risk at the main stages of the NPP construction life cycle: the area of minimal risk; the area of average risk; the area of increased risk; the area of critical risk; the area of unacceptable (catastrophic) risk (Fig. 3). In order to implement the strategic goals of the Rosatom State Corporation it is proposed to separately identify and analyse the risks that may hinder the implementation of a particular NPP construction project, namely:

1. increasing the share in the international nuclear power markets;
2. reduction of production costs;
3. reduction of production process time;
4. introduction of new products to the market;
5. global leadership in the field of technology [10].

Analysis of risk through the membrane of strategic objectives of Rosatom allows adopting a conceptual economic and mathematical model of risk management of realization of a unique NPP facility by probabilistic-functional dependence:

$$P_{(t)}^{nad} = \bigcup_{w,i,j=1} \{V_{ij}\}, \{T_{real(i+1)}\}, \{X_i\}, \{R_{tpn}^n, K_{fin}^n, K_{tr}\}, N_j, E_j, Q(\tau) \rightarrow max, \quad (2)$$

where  $P_{(t)}^{nad}$  is effectiveness (organizational and technical reliability) of NPP implementation;  
 w, i, j is the number of hierarchical levels from 1 to N (macro-, meso- and micro-levels);  
 $V_{i,j}$  is integral indicator of the aggregate risk;  
 $T_{real(i+1)}$  is time elapsed since the beginning of strategy implementation to  
 $X_i$  is the full life cycle of the NPP;  
 $(R_{tpn}^n, K_{fin}^n, K_{tr})$  shows total resources (physical, financial, labor) required for decision making;  
 $N_j$  is a set of alternatives defining the problem situation;  
 $E_j$  is preference function for choosing a solution option;  
 $Q(\tau)$  is a set of time parameters on the interval (0,1).

## CONCLUSIONS

The analysis of the methodological recommendations for improving the system of preparation and execution of construction works for large and technically complex industrial facilities allowed the authors to suggest ways to improve the organizational and technical reliability of designed solutions in the conditions of aggregate investment risk. Thus, the authors develop and apply their own concepts and methods of reliability and risk assessment. The essence of the membrane method of risk assessment for NPPs developed by engineer Denis Sezemin is that each stage of the project life cycle can be presented as a membrane layer, where one or another type of risk appears, which further contributes to the aggregate investment risk ( $R_{inv}$ ), supplements it and transfers (grows, “sprouts”) to the next layer. Here there is

some similarity with physical-technical relation and behaviour of a membrane with its oscillation and attenuation, i.e., the risk has a possibility to pass through all layers of the membrane or, conversely, end on a certain layer, having had its impact. This implies that different types of risks corresponding to the aggregate investment risk can grow, appear or disappear at any stage, starting from the first and ending at the top of the layers. With the help of the necessary and recommended membrane principle of physical-type action throughout the life cycle of the project, the author of the Membrane Method proposes to develop software based on the impact of investment risk on the final target parameters of the whole system. The target parameters of the NPP construction system are: time parameter (duration), cost parameter (economic efficiency), quality parameter, and technical safety parameter, which are associated with the four corners of the square in the form of some volumetric structure. This allows visualizing a graphical representation of the dynamics of risk manifestation in time, displaying the main aspects of the problem under study:

- the fact of risk existence;
- the stage of risk occurrence;
- the stage of risk impact termination;
- impact of each of the risks separately on the system of the organizational and technical reliability of the project at major stages of the project life cycle;
- impact of all types of risks as an aggregate investment risk on the system, assessing it by four “corner” parameters;
- development of risk management methods using the diversification method with mechanisms for taking compensating measures.

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