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Research paper

Risk assessment of prospective investment projects for the construction of nuclear power plants abroad

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Abstract

The article deals with the development of nuclear energy, classification of risks, approaches to risk assessment of investment projects of NPP construction abroad. Presented integrated methodology for assessing the risks of nuclear investment projects is based on the recommendations of the United Nations Industrial Development Organization (UNIDO), the International Atomic Energy Agency (IAEA), the sectoral methodological recommendations of the State corporation Rosatom. A way of accounting for risks in the calculation of economic efficiency is proposed. Calculations have been made for several real NPP construction projects (Rooppur NPP in Bangladesh, Astravets NPP in Belarus, Hanhikivi NPP in Finland). Analysis of the results of these projects shows that, taking into account all types of risks, its investment attractiveness has significantly decreased.

Keywords: *NPP Construction, Investment Project, Risk-Assessment, Economic Efficiency, Integrated Methodology.*

1. Introduction

At present, nuclear power is one of the most large-scale industries: as of mid-2017, 448 power units operate in the world, and another 58 are under construction. Successful implementation of major investment projects on the NPP construction provides opportunities for dynamic development of the nuclear industry. State Corporation Rosatom is a world supplier of reactor technology, its ten-year portfolio of foreign orders exceeded $110 billion in 2015. Huge scale and variety of projects in the nuclear sphere are associated with the emergence of risks in their implementation. The issue of risk-reduction in each project is crucial [1].

Determining economic efficiency of the investment project that includes assessment of the risks caused by inconsistencies in the regulatory framework, underdeveloped infrastructure, uncertain macroeconomic conditions during implementation, etc. is an important step in the decision-making process concerning the choice of the NPP project. Atomic projects have much in common with projects in traditional energy sector. However, they have a number of special characteristics that lead to increased risks in their implementation.

There is no unified approach to economic efficiency evaluation of NPP construction projects in international practice [2]. There are two main types of recommendations, as well as the methodology of project companies. Any methodology for assessing economic efficiency should be in line with the international recommendations of the IEA/NEA with the OECD, the PMBOK (project management body of knowledge), and the requirements of ISO 31000: 2009, ISO/IEC 31010: 2009, ISO GUIDE 73: 2009.

The change in the main criterion of the project's economic efficiency was a turning point. Previously, this criterion was the cost of a unit of installed capacity, calculated on capital costs. It is now considered to be the cost of a unit of electricity produced, calculated on the full life cycle of a NPP. Taking into account these objective changes in economic processes it is necessary to develop a methodology for assessing the economic efficiency of nuclear projects.

2. Models and Methods

2.1. Integrated methodology for assessing the risks of nuclear investment projects

This article deals with a mathematical model of the integrated risk assessment, which was based on the named approach [3]. Identification and qualitative risk analysis is undertaken using special technologies, taking into account the specifics of the implementation of projects in nuclear energy. Bayesian analysis is used to assess information gains. Transition to the quantitative risk analysis accords with the method of risk indexes described in ISO 31010: 2009.

Author's risk register that is used for the assessment is based on the approach to the definition of risks in the projects of Standard & Poor's [4], however it is structured and finalized taking into account the features of the NPP complete life cycle (Table 1) [5]. For the first time information risk and incomplete production of electric power have been highlighted in the evaluation of projects.

Table 1: Register of risks of investment projects for NPP construction

Risk group	Risks
Project risk (Rpr)	Technological (Rta) Market (Rra) Counteragent (Rak) Legal (Rnp) Financial (Rfa)
Systematic risk (Rst)	Country (Rst)
Risk of external impact (Rei)	Force majeure (Rfm) Информационные (Rинф)
Specific risk	Incomplete power generation at NPP (Rig)

The project risk index is calculated according to the formula (1):

R = Rpr × Wpr + Rst × Wst + Rei × Wei,
with Wpr + Wst + Wei = 1. (1)

To do this, the assessment is conducted in the following steps.
The design risk Rpr is determined by the method of expert assessments based on the approach of the international rating company Standard & Poor's [4], adapted for nuclear energy. There are five main groups of risks: technological risks; market risks; counteragent risks; legal risks; financial risks [6]. Each group is assigned a risk index. The value of the risk index varies from 0 to 1, depending on the design of the project in each direction. Thus, indices are determined for all five types of project risks Rta, Rra, Rak, Rnp and Rfa. Then the relative weights of these indices are determined. The value of the project risk index is calculated from the formula (2):

Rpr = Rta × Wta + Rra × Wra + Rak × Wak + Rnp × Wnp + Rfa × Wfa, with Wta + Wra + Wak + Wnp + Wfa = 1. (2)

An assessment of the systematic risk Rst is carried out, which takes into account a combination of political and macroeconomic conditions. The research of such issues is carried out by international analytical companies that consider the following ratings: Country Credit Rating (CCR), Country Rating by Economic Freedom (IEF), Country Risk Rating (International Country Risk / ICR) [6]. Risk indices for these indicators are determined: Rccr, Rief and Ricr. The relative weights of these indices are proposed to be equal to 0.33. The systematic risk index is proposed for a specific country as a weighted average (3):

Rst = Rccr × Wccr + Rief × Wief + Ricr × Wicr,
with Wccr + Wief + Wicr = 1. (3)

The risk of external impact Rei is assessed. This group includes the risk of occurrence of force majeure situations. Using the expert data, the complexity of the NPP construction project is determined on a scale from 0 to 1, and then the force majeure risk index Rfm is determined numerically equal to the established complexity of the project. Along with the force majeure risk, Rinf that stands for information risk should be taken into account as in the age of the development of information technology it begins to play a big role. The relative weights of risk indices of this group are determined. According to the formula of the average weighted value, the risk index of external impact is calculated (4):

Rei = Rfm × Wfm + Rinf × Winf, with Wfm + Winf = 1. (4)

The overall risk index of the project R is determined by summing the values obtained for the different types of risks with the corresponding weights (5):

R = Rpr × Wpr + Rst × Wst + Rei × Wei,
with Wpr + Wst + Wei = 1. (5)

There are risks of incomplete generation of electric power during NPP operation. Specificity of the NPP operating mode is the need for regular scheduled preventive maintenance. In addition, plants are subject to abnormal situations. Such situations can lead to power unit stops, a decrease in its capacity, or pass without interference into the power generation process [7].
This article proposes an original methodology for calculating the planned electricity generation at NPPs, taking into account the risks of incomplete generation of electricity due to technological measures and emergency situations during operation (6).

Et = Wpr × ICUFpr × 8760 × (1 - f(t) / 100). (6)

There are Et is the electricity produced per year (MWh); Wpr is the design capacity of the nuclear power plant (MW); ICUFpr – installed capacity utilization factor; 8760 - total number of hours in a year; f(t) is a function characterizing the deviation of the real volume of electric power generation from the projected one (Fig.1).

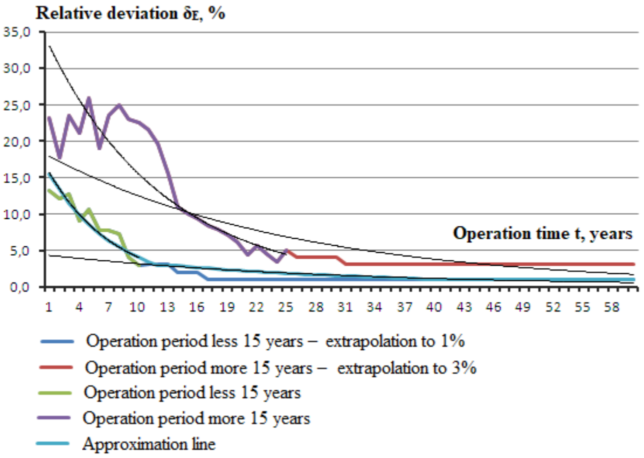

Fig. 1: Relative deviation of the real volume of electricity generation and the project volume

The performed comparative analysis of the calculation results using the model for assessing the risk of incomplete generation of electricity at NPPs with VVER-1000 reactors and without its use shows that the clarification reaches approximately 30% for net discounted income and 30% for a discounted payback period. The results of the analysis are given in Table 2.

Table 2: Results of accounting by the model for assessing risk of incomplete generation

Parameter	Value without model	Value with model	Abs. change	Rel. change
NPVef, mln. $	2680,36	1806,27	-874,09	-32,6%
IRR, %	13,62	12,35	-1,27	-9,3%
DPPef, years	18	23	5,00	27,8%
PI ef	2,89	2,67	-0,22	-7,6%

2.2. Comparative risk analysis of NPP projects

A comparative analysis of the overall risks of the projects was carried out for the implemented Russian NPP construction projects abroad. This is the Kudankulam NPP in India; Bushehr NPP in Iran and Tianwan NPP in China. For each project, real data were calculated taking into account the presented mathematical model of complex risk assessment. The calculations took into account statistical indicators in the USA [8].
Kudankulam NPP (2 VVER-1000 units, the project "AES 92") has been under construction in India since 2002. The cost of the Kudankulam NPP project in 2003 was estimated at $3 billion. In 2014 prices, the cost of one power unit with fuel supply was $3.24 billion. At the same time, the real costs in 2014 for the first power unit of the Kudankulam NPP were estimated at $3.8 billion [9]. The main economic losses are associated with the delay in construction and commissioning. During this time, the components for the NPP have risen significantly. In addition, it is worth noting a long delay in resolving the issue of the liability agreement in the event of an incident at the NPP. Prior to the adoption of the Law

on Civil Liability for Nuclear Damage (2010) and the Rules on Civil Liability for Nuclear Damage (2011), there was no specific relevant legislation in India.

The construction of the Bushehr nuclear power plant (1 VVER-1000 unit, model V-446) started in 1998. In August 2012, as part of the power start-up, the reactor installation was put out at 100% capacity. The cost of the project in 1998 was estimated at $1 billion for the power unit. In 2013 prices, the cost of the power unit with fuel supply was $3.37 billion. At the same time, real costs in 2013 for the power unit of the Bushehr NPP were estimated at $4 billion [10]. The main economic losses are related to the technical solution for the project and the dismantling of the old equipment, the delay in construction and commissioning.

The Tianwan NPP (2 VVER-1000 units, the project "AES 91") was built in China. Construction work on the site began in 1999. The first unit was put into commercial operation in December 2006, the second - in May 2007. The cost of the project in 1999 was estimated at $3 billion. In 2007 prices, the cost of one block with fuel supply was $3.13 billion. Real costs in 2007 year at the first power unit of the Tianwan NPP were estimated at $3.5 billion [11]. The main economic losses are associated with the delay in construction and commissioning.

With the help of the proposed integrated methodology for risk assessment, the main risk groups of the three projects were identified. The results are presented in Table 3.

Table 3: Risk matrix for Kudankulam, Bushehr and Tianwan NPPs projects

Risk index	**Value**		
	Kudankulam NPP	**Bushehr NPP**	**Tianwan NPP**
Project risks			
Risk index *Rta*	0,8	0,8	0,8
Risk index *Rra*	0,8	0,7	0,6
Risk index *Rak*	0,5	0,5	0,5
Risk index *Rnp*	0,6	0,7	0,4
Risk index *Rfa*	0,6	0,6	0,5
Systematic risks			
Risk index *Rccr*	0,49	0,66	0,32
Risk index *Rief*	0,53	0,63	0,35
Risk index *Ricr*	0,47	0,61	0,36
Risks of external impact			
Risk index *Rfm*	0,8	0,80	0,71
Risk index *Rinf*	0,63	0,55	0,18
Risk groups			
Project risk index *Rpr*	0,68	0,67	0,57
Systematic risk index *Rst*	0,51	0,63	0,35
Risk of external impact index *Rei*	0,67	0,64	0,33
Overall risk index *R*	**0,62**	**0,65**	**0,46**

2.3. Estimation of the discount rate

Table 4: The main technical and economic characteristics of the completed Russian projects abroad

Characteristic / Projects	**Kudankulam NPP**	**Bushehr NPP**	**Tianwan NPP**
NPP Project	AES-92	V-446	АЭС-91
Electric power (net), MW	917	915	970
Installed capacity utilization factor (ICUFpr)	83%	83%	85%
Planned construction period, years	6	6	6
Real construction period, years	13	11	8
Lifetime, years	40	40	40
Planned discount rate *d0*	8,5%	8,5%	9,0%
Risk-free rate *Rf*	5%	5%	5,2%
Price of electricity, cents per kWh	6	8,4	7
Planned costs per unit, bln $	3,24	3,37	3,13
Real costs per unit, bln $	3,8	4,0	3,5
Costs increase	17,3%	18,7%	11,8%

Table 4 shows that there is a correlation between the overall project risk index and the relative change in the project implementation cost. It is this dependence that the coefficient β used in calculating the effective discount rate should reflect.

For the Kudankulam NPP project, an economic effect was estimated for the NPV indicator for 2047 (project construction period and operating life) at the design discount rate d0 = 8.5%. Value NPVfact = $-415.72 million for the year 2047. The discount rate (def) was calculated on the project data, under which the economic effect of the NPV for 2047 will be the same as in the actual data version [12]. Thus, the value of def = 11.44% is obtained. Relative error of calculation δ (NPV) = 0,06%. Fig.2 shows NPV charts calculated taking into account the design (d0) and effective discount rates (def).

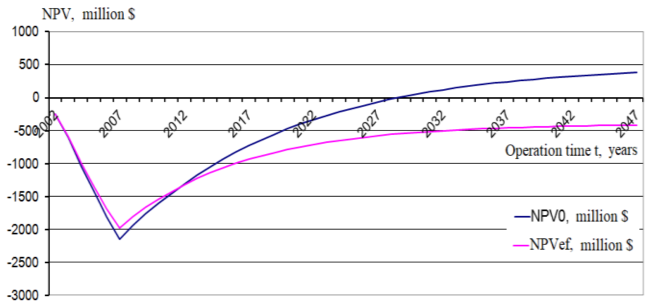

Fig. 2: NPV0 and NPVef dependencies on time for the Kudankulam NPP project

Based on the presented diagrams, it can be concluded that the project was originally planned to be profitable, however, due to the postponement of the terms and the growth of construction costs, the project became unprofitable.

Similar calculations were also carried out for the projects of Bushehr NPP and Tianwan NPP [12]. Table 5 summarizes the data on three Rosatom projects abroad, as well as the value of the coefficient β. The loss of a number of projects and the decrease in the planned profit is indirectly confirmed by statements that Russia undertook all three projects to maintain the technical base, as well as proceeding from the solution of political and reputational problems.

Table 5: Planned and effective discount rates

Parameter	**Kudankulam NPP**	**Bushehr NPP**	**Tianwan NPP**
Planned discount rate d0	8,5%	8,5%	9,0%
Effective discount rate def	11,44%	11,76%	11,15%
Overall risk index R	0,62	0,65	0,46
β - coefficient	1,84	1,93	1,56

Thus, the dependence of the coefficient β(R) was determined experimentally (7):

$$\beta(R) = R^2 + 0{,}76 * R + 1. \quad (7)$$

3. Determination of economic efficiency of new projects

The results of the calculation of the characteristics of the investment project for the construction of a two-unit NPP under the NPP-2006 project with VVER-1200 reactors in Bangladesh according to the proposed integrated methodology for determining the economic efficiency of projects, taking into account the mathematical model of integrated risk assessment, the model for estimating the risk of incomplete generation of electricity and the method for determining the effective discount rate are given in Table 6.

Table 6: Parameters of investment NPP construction project in Bangladesh

Parameter	Value	Rel. change
Planned discount rate *d0*	10,5%	37,1%
Effective discount rate *def*	14,4%	
Planned net present value, *NPV0*, mln $	3653,9	-50,4%
Effective net present value, *NPVef*, mln $	1810,4	
internal rate of return, *IRR*, %	29,0%	-
Planned discounted payback period, *DPP0*, years	8	12,5%
Effective discounted payback period, *DPPef*, years	9	
Planned Profitability Index, *PI0*	2,35	-40,0%
Effective Profitability Index, *PIef*	1,41	

Analysis of the results of this project shows that, taking into account all types of risks, its investment attractiveness has significantly decreased.
Also, calculations of the economic efficiency of two more promising investment projects for the construction of nuclear power plants - in Belarus (2 units) and Finland (1 units) have been made [13]. The results are presented in Table 7.

Table 7: Parameters of investment NPP construction project in countries

Parameter / Project	Rooppur NPP (Bangladesh)	Astravets NPP (Belarus)	Hanhikivi NPP (Finland)
Reactor	VVER-1200	VVER-1200	VVER-1200
Electric power (net), MW	1160	1190	1190
Planned construction period, years	6	6	6
Lifetime, years	60	60	60
Planned discount rate *d0*	10,5%	10,5%	10,5%
Overall risk index *R*	0,45	0,39	0,32
Risk-free rate *Rf*	5%	5%	5%
Effective discount rate *def*	14,42%	13,01%	12,38%
NPV0 / NPVef, mln. $	3654 / 1810	2434 / 1641	1466 / 802
IRR, %	29,0%	35,8%	16,5%
DPP0 / DPPef, years	8 / 9	8 / 8	13/ 15
PI0 / PIef	2,35 / 1,41	3,79 / 2,74	4,31 / 3,09

4. Conclusion

The use of the proposed integrated methodology for assessing the economic efficiency of NPP construction projects in different countries, taking into account the original models, clarifies the results of existing approaches. It allows to make managerial decisions in the process of analysis and planning of foreign projects with a higher degree of accuracy of forecasting. The original methodology allows to obtain a more accurate assessment of investment characteristics in the implementation of projects and identify areas of high risk.

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