Research Paper
This paper is based on Global 2017 presentation.

https://doi.org/10.7733/jnfcwt.2019.17.1.47

Multi-criteria Comparative Evaluation of Nuclear Energy Deployment Scenarios With Thermal and Fast Reactors

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(Received March 5, 2018 / Revised August 14, 2018 / Approved January 24, 2019)

The paper presents the results of a multi-criteria comparative evaluation of 12 feasible Russian nuclear energy deployment scenarios with thermal and fast reactors in a closed nuclear fuel cycle. The comparative evaluation was performed based on 6 performance indicators and 5 different MCDA methods (Simple Scoring Model, MAVT / MAUT, AHP, TOPSIS, PROMETHEE) in accordance with the recommendations elaborated by the IAEA/INPRO section. It is shown that the use of different MCDA methods to compare the nuclear energy deployment scenarios, despite some differences in the rankings, leads to well-coordinated and similar results. Taking into account the uncertainties in the weights within a multi-attribute model, it was possible to rank the scenarios in the absence of information regarding the relative importance of performance indicators and determine the preference probability for a certain nuclear energy deployment scenario. Based on the results of the uncertainty/sensitivity analysis and additional analysis of alternatives as well as the whole set of graphical and attribute data, it was possible to identify the most promising nuclear energy deployment scenario under the assumptions made.

Keywords: Thermal reactors, Fast reactors, Closed nuclear fuel cycle, MCDA, Uncertainty

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1. Introduction

When performing integrated analyses to support the decision making process in regard to the selection of the most promising nuclear energy development scenario and assessment of the nuclear energy role in sustainable development along with planning nuclear energy programs, it is necessary to evaluate a number of key performance indicators (KIs) for different assessment areas (resources, economy, proliferation resistance, safety, waste management, infrastructure etc.). Based on this information, it would be possible to make conclusions about the potential and performance of the considered alternatives [1]. As a rule, the KIs are conflicting in nature: an improvement in the value of one indicator, when passing from one alternative to another, entails a deterioration in other indicators.

The ranking of alternatives and selection of the most promising one according to a set of KIs requires aggregation of expert judgments and can be performed in a non-formalized way, i.e., based on expert intuition and experience or using formal decision-making support methods. The latter option seems to be more reasonable because it gives an opportunity to structure the process of comparing the considered alternatives, presenting pros and cons of each of them on a well-reasoned quantitative basis, which makes it possible to justify the selection of the most balanced trade-off alternative. A correct account and assessment of the impact of subjective and objective uncertainties on the ranking results can also improve the validity of judgments.

Provided that the alternatives under consideration are explicitly defined by means of an estimated set of KIs, a comparison and selection of the most attractive alternative can be performed using the multi-criteria decision analysis (MCDA) methods such as, MAVT/MAUT, AHP, TOPSIS, PROMETHEE, which are widely used to support decision-making in various subject areas, including nuclear engineering. These methods are most widely used within the frameworks of international collaborative projects under the auspices of the IAEA and NEA/OECD as well as in studies conducted by the US Department of Energy [2]. As part of the collaborative project “Key Indicators for Innovative Nuclear Energy Systems” (KIND) of the INPRO/IAEA section, recommendations were elaborated on how to use these methods for a comparative analysis, evaluation of performance and sustainability of nuclear energy systems (NESs) and components thereof. These recommendations can be applied to a wide range of problems on comparing NES options at the technology/scenario levels [3,4].

2. Background assumptions

Experts from the JSC “NIKIET” and ITCP “PRORYV” [5–8] in a series of studies have assessed a representative set of 6 KIs (Table 1), which characterize both the performance of material flow management in the nuclear fuel cycle (NFC) and economic performance of 12 NES deployment scenarios with thermal and fast reactors in the Russian Federation (Table 2).

All the indicators selected as compromise ones by different national subject matter experts performing evaluations can be considered as independent ones and reflecting national priorities in regard to nuclear power development. These indicators characterize different aspects related to the realization of the considered NES deployment scenarios. In this regard, it is not possible to specify a single common global performance indicator in which all the considered performance measures could be converted; therefore, a multi-criteria decision-making framework should be applied. The use of this analytical framework is also necessary due to multiple unquantifiable or subjective factors within such priorities as the NES deployment, attitude to risk, and importance of different performance indicators which can be varied for different expert groups. These factors are to be incorporated and considered.

The processed data on KI values for a given set of scenarios, which were used in the present study, are shown

Table 1. Key performance indicators

Abbr.	Key indicators	Units	Groups of key indicators
KI-1	Integral consumption of natural uranium	kt	Uranium consumption
KI-2	Integral SNF reprocessing volume	kt	Waste management performance
KI-3	Accumulated SNF/HLW volume for disposal	kt	
KI-4	Integral absolute expenditures	Bill. of US doll.	Economic performance
KI-5	Reserve for the SNF/RW management	Mill. of US doll.	
KI-6	Fuel component of the cost of electricity	cent/kWh	

Table 2. NES deployment scenarios

No.	Description of NES deployment scenarios
1	Once-through NFC, only thermal reactors
2	The same as no.1 + MOX from plutonium reserve
3	Only thermal reactors, complete SNF reprocessing into MOX
4	Thermal and fast reactors without thermal reactors SNF reprocessing
5	The same as no. 4 with a 3-year external NFC of thermal reactors
6	The same as no. 4 with an operation time of VVER reactors of 60 years
7	Thermal and fast reactors with VVER SNF reprocessing
8	The same as no.7 with the reprocessing delayed by 30 years
9	Thermal and fast reactors with complete thermal reactors SNF reprocessing
10	Thermal and fast reactors, breeding only in the fast reactors core
11	Thermal and fast reactors, breeding in the fast reactors core and in the side blanket
12	Thermal and fast reactors, breeding in the fast reactors core and in the side and axial blankets

Table 3. Performance table

KIs	Units	NES options											
		1	2	3	4	5	6	7	8	9	10	11	12
KI-1	kt	2572	2560	1904	917	1021	941	755	779	735	958	764	557
KI-2	kt	2.4	3.1	187.9	107.2	104.1	103.6	142.5	143.1	168.3	105.7	187.8	262.4
KI-3	kt	260	260	72	73	74	74	41	41	16	76	75	74
KI-4	Bill. of US $.	5316	5316	5100	4433	4457	4440	4433	4433	4450	4443	4707	4951
KI-5	Mill. of US $	2131	2087	1113	998	1056	1022	738	744	690	994	987	987
KI-6	cent/kWh	1.05	1.10	0.94	0.74	0.76	0.74	0.81	0.74	0.80	0.75	0.84	0.95

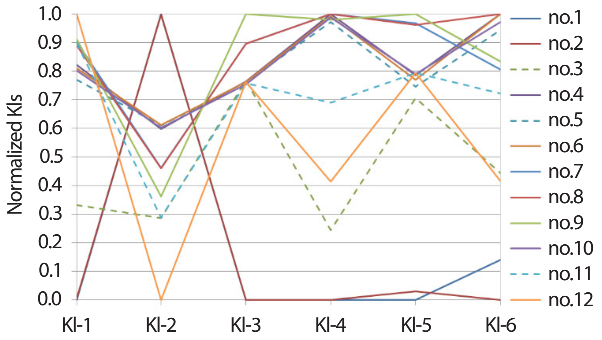

Fig. 1. Normalized KI values
(dash lines – dominated options, see comments below).

in Table 3. It is assumed that all the KIs should be minimized. Based on these data, this paper presents the results of a MCDA-based comparative analysis of these scenarios to demonstrate the potential of the relevant decision support toolkit for a quantitative comparison and ranking of the national NES options.

The key indicators were evaluated using a dynamic system model constructed within the USM-1 System Model Generator software tool. The NES structure includes aggregated components that represent the NFC front-end and back-end, two types of nuclear power plants with thermal reactors (VVER and RBMK) and fast reactors (fast reactors with inherent safety and a breeding ratio of ~1 and fast breeder reactors), centralized facilities for producing fresh fuel for thermal reactors, centralized facilities for reprocessing SNF from thermal reactors, and near-plant NFC facilities that reprocess SNF from fast reactors and produce fresh fuel for fast reactors.

Consideration is given to the scenarios of large scale growth of NESs with a total installed nuclear capacity rising to ~190 GW by 2050 and to 390 GW by 2100, including scenarios based on fast reactors with inherent safety and a breeding ratio of ~1 in a closed NFC, scenarios with different options for thermal reactor SNF reprocessing (including options assuming utilization of MOX fuel in thermal reactors) and with account for the possibility of extended fuel breeding (Table 2).

Assumptions are also made of prompt deployment of fast reactors (including enriched uranium reactors) into service, uranium saving due to the gradual replacement of traditional thermal reactors by inherently safe fast reactors operating in a closed NFC with the transition to equilibrium "dirty" fuel that retains minor actinides and some fission products, establishing the conditions for radiation equivalent waste disposal and minimum duration of the external NFC with the corresponding minimization of accumulated SNF and its reprocessing [9].

The normalized KI values for the considered scenarios are presented in Fig. 1 in the value path format (the best KI relative value is 1)[1]. As can be seen, there is no alternative surpassing the others in terms of its set of KIs: each alternative has certain advantages over the others. For this reason, the ranking of scenarios requires an aggregation of KIs based on expert judgments.

3. MCDA methods applied in the study

Multiple criteria decision analysis methods are a support tool intended to help decision makers, who are faced with numerous, sometimes conflicting, assessments, to highlight conflicts and perform proper trade-offs during the decision making process. Multiple criteria decision analysis problems consist of a finite number of alternatives, explicitly known at the beginning of the decision support process. Each alternative is represented by its performance on multiple criteria. The problem may be defined as searching for the best alternative from the decision maker's viewpoint or finding a set of acceptable tradeoffs among the alternatives [10, 11].

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[1] The normalized values of KIs were evaluated according to the formula: $x^{max} - x / x^{max} - x^{min}$, where x^{max} and x^{min} are the minimal and maximal values of KIs for the given set of NES options, x is the value of KI for the specific NES option.

A large number of MCDA techniques have been developed to deal with different kinds of problems. The assessments presented in this study were made using the following well-known and widely used MCDA methods: MAVT (Multi-Attribute Value Theory), MAUT (Multi-Attribute Utility Theory), TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), AHP (Analytic Hierarchy Process), and simple scoring model (SSM) [12-15]. They are based on different methodologies; therefore, their simultaneous use may lead to a judgment about the stability and robustness of ranking results with respect to the selection of a decision rule, which is important for increasing the validity of judgments.

Within these methods, it is assumed that the criteria values and weights are real undistributed (i.e., nonrandom) numbers. In such methods, uncertainties are examined by means of a sensitivity analysis: generally, by applying it to changes in the values of weights. In making comparisons in this study, model assumptions were selected according to the recommendations made by the INPRO/IAEA section of the KIND collaborative project, which have proven their efficiency in carrying out national case studies [4].

The approach implemented in this study involves several different MCDA methods which may facilitate thorough understanding, recognizing and analyzing the problem, providing an additional sensitivity analysis of the obtained ranking results to the methods used that increase the study confidence level. Application of a wide landscape of different methods may have a significant influence on subsequent decision making and help a decision maker more thoroughly understand and analyze the problem, achieving consistency in judgments and estimates. It also necessitates examining the stability and robustness of the ranking results to different assumptions. Although the ranks of alternatives may vary for different MCDA methods, an analysis of the problem by different methods may play a significant role in the interactive process of understanding the problem and identifying its main features and it may demonstrate that different methods may provide noncontradictory results.

MAVT was chosen in this paper as the reference method, because attributes are mutually preference-independent and, in this case, MAVT offers a possibility to implement the measurable value functions and apply the additive rule for a judgment aggregation (additive form of the multi-attribute value function). Moreover, MAVT provides an assessable resolution grade of ranked options and feasibility of breaking-down the overall score into partial scores for composed indicators. These features facilitate an interpretation of the results.

MAUT is a theory closely related to MAVT, which is based upon the expected utility theory. MAUT extends MAVT in using probabilities and expectations to deal with uncertainties. A criterion value uncertainty is represented in MAUT by a random variable with the probability density function. The overall utility for the alternatives can be considered in this case a random variable. The alternative ranking within MAUT is based on the comparison of expected utilities: one alternative exceeds the other if the mathematical expectation of a utility function for the first alternative is greater than that of the other. Among all the other MCDA methods, MAVT and MAUT have been applied to a wide range of decision making problems in the area of multi-criteria comparative assessments of nuclear reactors, related NFCs and NESs. Monotonically decreasing linear functions were chosen as the single-attribute value and utility functions for the considered KIs.

TOPSIS is based on a concept that the chosen alternative should have the shortest distance from the most desirable (ideal, or positive ideal) solution and the longest distance from the less desirable (anti-ideal, or negative ideal) solution. The ideal solution is a solution which has the best level for all indicators considered. The negative ideal solution is a solution which has the worst indicator values. TOPSIS selects the solution that is the closest to the ideal solution and farthest from the negative ideal solution.

Table 4. Domination table

Dominated scenarios	Dominating scenarios
3	7, 8, 9
5	6
11	7, 9

The PROMETHEE method belongs to the so-called outranking methods which imply forming an ordered relation of a given set of alternatives. The outranking methods are based on a pairwise comparison of alternatives for each criterion under consideration, with subsequent integration of the obtained preferences according to a chosen algorithm. In the PROMETHEE method, it is required to choose a preference function defined in the range from 0 to 1, with specified indifference and preference thresholds.

AHP is a method used to organize and examine multifaceted decisions assuming decomposition of the decision problem into a hierarchy of more easily comprehended sub-problems and to apply pairwise comparisons to various hierarchy elements. To obtain estimates by the AHP method, matrixes of pairwise comparisons were filled in accordance with the AHP algorithm based on the weights and performance table specified in the AHP pairwise comparison scale.

Additionally, the simple scoring model (SSM) was used for comparison, which is the simplest MCDA method applicable only when all data are expressed in exactly the same units. In this method, the overall score of an alternative is defined as the weighted sum of the alternative decision indicator or attribute values.

4. Identification of non-dominated scenarios and weighting options

One of useful preliminary stages within the MCDA approach is to determine a set of non-dominated scenarios. A 'dominated' scenario means that its entire set of KIs is worse than those of scenarios that dominate it. Dominated options may be excluded from further consideration since their overall scores will always be lower than the overall scores for the options which dominate them. It facilitates the comparison by minimizing options under consideration and makes the ranking results more stable. The formal definition of the set of non-dominated options $P_f(X)$ is as follows:

if X is a set of choices, and $f = (f_1, f_2, ..., f_m)$ is the vector of optimality criteria, each of which, let us assume, is to be maximized [2]. Then

$P_f(X) = \{x^* \in X \mid$ there does not exist $x \in X$ such that $f_i(x) \geq f_i(x^*)$, $i = 1, ..., m$, $f(x) \neq f(x^*)\}$.

The benefit of this stage is that there is no need to determine the weighting factors. However, the identification of the set of non-dominated scenarios does not allow for their ranking; therefore, it is necessary to define the type of a decision rule and the values of weights reflecting the relative importance of KIs for experts and decision-makers.

The evaluations show that the dominated options in the considered set are Options 3 and 11, which are dominated by Options 7, 8, 9 and Options 7 and 9, respectively, as well as Option 5 which is dominated by Option 6 (see Table 4). Fig. 1 reflects this fact showing that the value path of the dominated scenario is below that of the dominating one.

The weighting factors were evaluated using the equal weights reflecting the situation where all KIs are equivalently important and there is no idea about their relative importance. The "equal weights" (or "mean weights") weighting option assumes that the weights are determined by the equation $w_i = 1/n$, where n is the number of key indicators [16,17]. This approach can be applied when there is no

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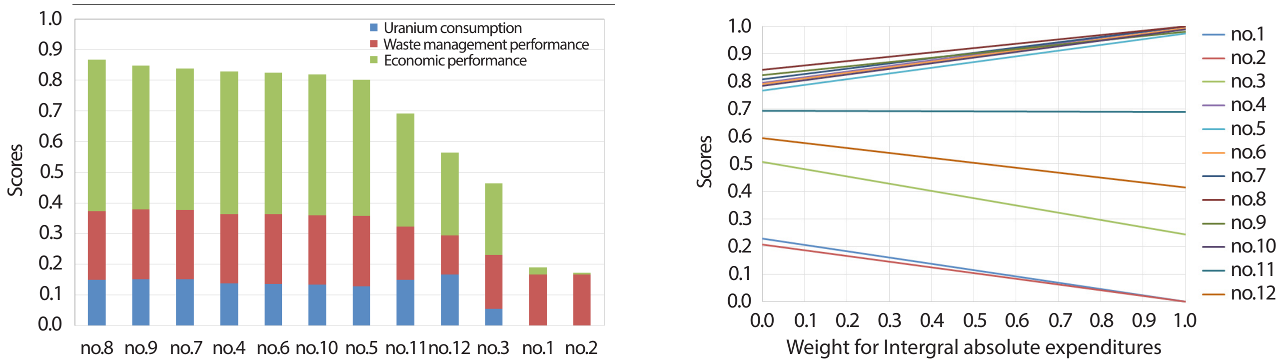
[2] A maximization problem can be transformed to a minimization one. For each of the objectives to be maximized, the conversion: max fi = −min(−fi) should be applied.

Table 5. Scenario ranking results using different methods

Rank	Scenario no.					Scenario group
	SSM	MAVT/MAUT	AHP	TOPSIS	PROMETHEE	
1	8	8	7	9	8	1
2	9	9	8	7	9	
3	7	7	9	8	7	
4	4	4	6	6	4	2
5	6	6	4	4	6	
6	10	10	10	10	10	
7	5	5	5	5	5	
8	11	11	11	11	11	3
9	12	12	12	12	12	
10	3	3	3	3	3	
11	1	1	2	2	1	4
12	2	2	1	1	2	



(a) (b)

Fig. 2. MAVT ranking results for equal weights with breakdown of the overall scores into high-level objectives scores (a), weights sensitivity analysis (b).

information from decision-makers and experts or information on the relative importance of criteria is not sufficient to reach a decision. However, even if no detailed information regarding expert weights is available, the "equal weights" judgement in combination with a detailed weight sensitivity analysis provides a chance to make a general conclusion regarding the attractiveness of the options in many different perspectives.

5. Comparison of ranking results using different methods

Table 5 shows the ranking results (ranks) of NES deployment scenarios obtained by using various MCDA methods for basic weighting options and their grouping. The NES deployment scenarios were combined into specific groups in an expert manner considering the closeness of their overall

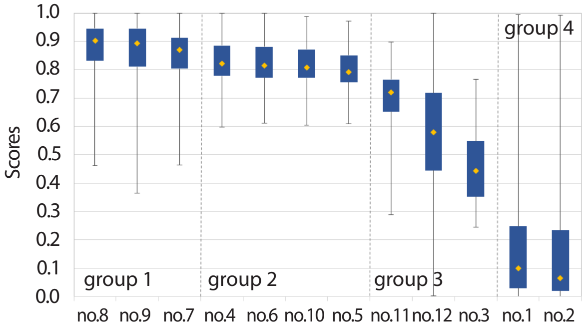
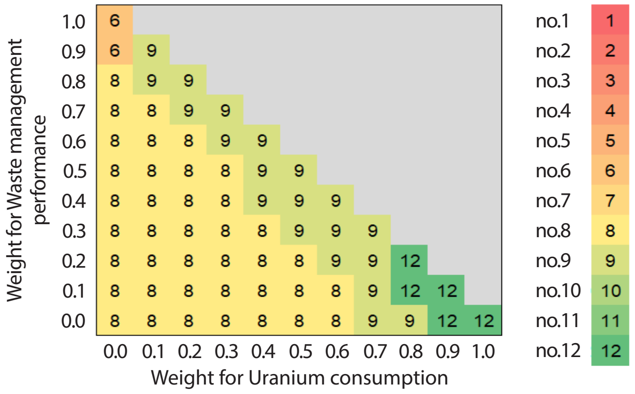


Fig. 3. Spreads in overall scores due to weighting factors (mean values, 25th, 75th percentiles, maximal and minimal values of overall scores are shown).



	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1.0	6										
0.9	6	9									
0.8	8	9	9								
0.7	8	8	9	9							
0.6	8	8	8	9	9						
0.5	8	8	8	8	9	9					
0.4	8	8	8	8	9	9	9				
0.3	8	8	8	8	8	9	9	9			
0.2	8	8	8	8	8	8	9	9	12		
0.1	8	8	8	8	8	8	8	9	12	12	
0.0	8	8	8	8	8	8	8	9	9	12	12

Fig. 4. Results of a sensitivity analysis with regard to high-level objectives weights.

scores and the preservation of scenarios within the relevant groups while changing the ranking methods. As can be seen, the use of different methods, despite some differences in ranking, leads to well-coordinated and similar results.

Note that the multi-attribute model (MAVT/MAUT methods) is the simplest and the most illustrative, for which the ranking results and results of sensitivity analysis in regard to weights (the so-called 'linear weights' approach) are shown in Fig. 2(a) and 2(b), respectively. Despite the fact that the ranking results of the scenarios in some way influence the weights of KIs, there are areas of stability where the ranking order is preserved over a wide range of changes in the weight values.

6. Accounting for uncertainty of KI relative importance

Sensitivity/uncertainty analyses are useful to examine the impact of uncertainties in input data on options' ranking. Such analyses are used to increase the clarity of alternative selection enabling decision-makers to reach a better understanding regarding the stability and robustness of results. Within the problem the only input data which were considered to be uncertain are weights. Sensitivity/uncertainty analyses in regard to weighting factors make it possible to understand the influence of weights assigned to alternative ranking (overall scores and ranks of alternatives).

The weight uncertainty impact on the ranking results can be examined using stochastic (probabilistic) variations of weights by determining the probability distributions of the scores. This allows for judgments regarding spreads in the overall scores in spite of the lack of detailed information usually gained by means of experts and stakeholders' elicitations in an iterative process. This approach, in particular, was implemented for the additive multi-attribute decision support model within a study carried out under the program of the US Department of Energy [18]. Potentially, this approach made it possible to rank scenarios in the absence of information regarding the significance of individual KIs as well as to determine the preference probability of a certain scenario.

Within this approach, it is assumed that all of the weights are randomly and uniformly distributed in the range from 0 to 1, constrained only by normalization conditions. In fact, the distribution function for generating imprecise information has minor influence on the statistic results. All the other assumptions were unchanged. For each weight combination, a MAVT-based evaluation should be performed to identify the overall scores of options. Associated probability distributions in overall scores can be obtained by means of Monte Carlo simulations. For a reliable estimation of probability distributions of the scores, 10,000 weight combinations have to be considered. The spreads in the overall scores due to uncertainties in weights may be represented

Table 6. Ranks of options taking into account unresolved uncertainties in weighting factors

Ranks	Options
1	8, 9, 7
2	4, 6, 10, 5
3	12, 11, 3
4	1, 2

as box-and-whisker plots that are indicative of the ranges of score changes for each option.

The ranking of NES deployment scenarios taking into account the uncertainties in weights is shown in Fig. 3 using the box-and-whiskers plot. The ranking results based on this approach are consistent with those obtained by the classical deterministic MCDA methods described above.

The results of uncertainty examinations in regards to weights assigned to the high-level objectives (namely, uranium consumption, waste management performance, economic performance, see Table 1) may be presented in the form of heat-mapping techniques for each of the three group of weights assigned to the high-level objectives. Such an analysis makes it possible to demonstrate a set of options, which can take the first rank, and appropriate weighting factor ranges providing this opportunity. The results of such an uncertainty analysis are presented in Fig. 4.

To obtain this chart, weights for the three high-level objectives (economic performance, waste management performance, uranium consumption) were simultaneously varied over a range from 0 to 1. As the weights must fulfil the normalization condition constraining their sum to 1, only two high-level objective weights can be independently chosen. The most promising NES options can be identified using MAVT with the corresponding combinations of high-level objective weights, each of which varied independently within the range from 0 to 1.

The coloured areas demonstrate the combinations of weights for which different NES options take the first rank (see Fig. 4). Thus, this picture demonstrates a map of preferences (weights) and provides a better understanding of how promising and robust each option ranking is in view of high-level objectives weights. The performed analysis shows that none of the high-level objective weights combinations may lead to Scenarios 1, 2, 3, 4, 5, 7, 10, and 11 at the top of the ranking order.

7. Results and discussion

Given the results of the uncertainty/sensitivity analysis and taking into account the additional analysis of alternatives using expert judgments and the whole set of graphical and attribute data under the above scenario assumptions, Scenarios 8, 9 and 7 may be considered as the most attractive. Scenarios 4, 6, 10 and 5 may be referred to the second most attractive group. Scenarios 11, 12 and 3 characterized by greater uncertainty can be integrated into the next most attractive group. Scenarios 1 and 2 are the least attractive ones (see Table 6). For further differentiation of the scenarios within each group it is necessary to have information regarding the preferences of experts and decision-makers on the relative importance of KIs.

However, even without taking into consideration this information, due to the performed analysis, it is possible to make the following conclusion as to the attractiveness of the scenarios provided that the scenario assumptions are true. Despite the high potential of fast breeder reactors (wide score scattering in scenario 12, see Fig. 3), it would be inappropriate to improve fuel breeding at the expense of economic KIs. At the same time, improvements of the performance and sustainability of NESs require reprocessing of spent fuel of thermal reactors with plutonium utilization in fast reactors without breeding. Nevertheless, due to the above-mentioned uncertainty in weights, there remains an open question in terms of reprocessing schedule and types of spent fuel of thermal reactors. It should be noted that the above conclusion is consistent with the findings presented in [3], where ranking was made for 11 global nuclear energy deployment scenarios estimated by 9 KIs.

Due to the limited scope of the study, the results of this analysis obviously cannot form the basis for substantiation of management decisions. However, it is the authors' opinion that it is quite sufficient to demonstrate the basic methodological aspects related to the application of MCDA methods for ranking NES deployment scenarios. The main benefit of an aggregation of expert judgments based on formal mathematical methods is that they give a possibility of structuring the discourse and organizing an efficient expertise to find the most prospective scenarios of nuclear energy development and demonstrate on a quantitative basis the merits and demerits of the compared alternatives which makes it possible to give well-reasoned judgments on their attractiveness [19, 20].

At the same time, for such an analysis to form the basis for management decisions and contribute to the elaboration of a concerted (trade-off) position on the most prospective scenarios of nuclear energy development, it is necessary to organize an expertise involving both proponents and opponents of different technical concepts for creating a consistent set of KIs which is supposed to be used for assessing scenarios, sets of scenarios and scenario assumptions. Particular attention should be given to the discussion of issues related to subjective and objective uncertainties and risks, which should be incorporated into an analysis, since both the new technologies and scenario conditions are characterized by significant uncertainties and risks. If such an expertise is realized, it would be possible (1) as a minimum, to achieve the objective based on a quantitative analysis, understanding of strengths and weaknesses of each alternative; and (2) as a maximum, should the participants of the expertise be constructively disposed, to select the most comfortable trade-off alternative.

8. Conclusion

The paper presents the results of a multi-criteria comparative evaluation of 12 feasible nuclear energy deployment scenarios with thermal and fast reactors in the Russian Federation. The evaluation was performed based on 6 performance indicators and methods of a multiple-criteria decision analysis in accordance with the recommendations elaborated by the INPRO/IAEA section of the International Atomic Energy Agency. It is shown that the use of different methods of a multi-criteria decision analysis (Simple scoring Model, MAVT / MAUT, AHP, TOPSIS, PROMETHEE) to compare the nuclear energy deployment scenarios, despite some differences in the rankings, leads to well-coordinated and similar results. Taking into account the uncertainties in the weights within a multi-attribute model made it possible to rank the scenarios in the absence of information regarding the relative significance of performance indicators and determine the preference probability for a certain nuclear energy deployment scenario. Based on the sensitivity and uncertainty analysis results and additional analysis of alternatives as well as the whole set of graphical and attribute data, it was possible to identify the most promising nuclear energy deployment scenario under the assumptions made.

9. Abbreviations

AHP: Analytic Hierarchy Process
IAEA: International Atomic Energy Agency
INPRO: International Project on Innovative Nuclear Reactors and Fuel Cycles
HLW: High-Level Wastes
KI: Key Indicator
KIND: Key Indicators for Innovative Nuclear Energy Systems
MAVT: Multi-attribute Value Theory
MAUT: Multi-attribute Utility Theory
MCDA: Multi-Criteria Decision Analysis
MOX: Mixed Oxide Fuel
NEA/OECD: Nuclear Energy Agency/Organization for Economic Cooperation and Development
NFC: Nuclear Fuel Cycle

PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluations
RW: Radioactive Waste
SNF: Spent Nuclear Fuel
SSM: Simple Scoring Model
TOPSIS: Technique for Order Preference by Similarity to the Ideal Solution
tHM: tonnes of Heavy Metal.

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