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Original Article

Analysis of Korea's nuclear R&D priorities based on private Sector's domestic demand using AHP

Yunbaek Lee [a, b, 1], Seungwook Son [c, d], Heejun Park [e, *]

[a] Department of Clean Power Planning, Korea Institute of Energy Technology Evaluation and Planning, Seoul, Republic of Korea
[b] Department of Technology Policy, Yonsei University, Seoul, Republic of Korea
[c] Energy&Environment Center, KMA Consultants Inc., Republic of Korea
[d] Energy and Environment Policy, Graduate School of Energy and Environment, Korea University, Seoul, Republic of Korea
[e] Department of Industrial Engineering, Yonsei University, Seoul, Republic of Korea

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ABSTRACT

Korea successfully achieved energy independence in the shortest period of time from being the poorest country in terms of energy 50 years ago through steady development of nuclear technology. In the past, the nuclear industry has been driven through government-centered policy development, public institution-based research, and industrial facility and infrastructure construction. Consequently, South Korea became a nuclear energy powerhouse exporting nuclear power plants to the UAE, surpassing the level of domestic technological independence. However, in recent years, the nuclear industry in Korea has experienced a decline in new plant construction since the Fukushima accident in Japan, which caused changes in public perspectives regarding nuclear power plant operation, more stringent safety standards on the operation of nuclear power plants, and a shift in governmental energy policy. These changes are expected to change the domestic nuclear industry ecosystem. Therefore, in this study, we investigate the priority of technology development investment from the perspective of experts in private nuclear power companies, shifting the focus from government-led nuclear R&D policies. To establish a direction in nuclear technology development, a survey was conducted by applying an analytic hierarchy analysis to experts who have worked in nuclear power plants for more than 15 years. The analysis items of focus were the 3 attributes of strategic importance, urgency, and business feasibility of four major fields related to nuclear energy: nuclear safety, decommissioning, radioactive waste management, and strengthening industrial competitiveness.

1. Introduction

Since the first commercial operation of domestic nuclear power generation in April 1978, the proportion of nuclear power generation in 2018 has decreased to 23.7%, i.e., a reduction of 10% from 2017, of which this proportion in 2018 reflects a decrease by more than half the level in 1987.(World Nuclear Power Market Insight [1]. This reduction in the proportion of nuclear power generation significantly affects the nuclear energy ecosystem, rendering it necessary for the government to establish policies considering internal and external environmental changes in the future when establishing a roadmap for nuclear power R&D.

The nuclear power field is a field requiring technology convergence, in which several engineering technologies are operating jointly; however, it is not easy to establish the priority in R&D by identifying the degree of importance between criteria of the priorities. Owing to the characteristics of the nuclear technology demanding rapid decision-making, nuclear technology development has been driven by government-led policy making and R&D planning hitherto.

In 2011, the Fukushima nuclear power plant accident changed the nuclear policy environment, and many countries worldwide have proposed various policies, such as strengthening nuclear safety measures, canceling the construction of new nuclear power plants, and prohibiting the life extension of decrepit nuclear power plants. In 2017, under the government of president Moon Jae-in, Korea announced an energy transition policy that cancels the

* Corresponding author. 50, Yonsei-ro, Seodaemun-gu, Seoul, 03722, Republic of Korea.
E-mail addresses: yblee1101@ketep.re.kr (Y. Lee), h.park@yonsei.ac.kr (H. Park).
[1] First author.

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construction of new nuclear power plants and not halts the life extension of decrepit nuclear power plants. This policy decision caused multiple changes in the nuclear industry ecosystem in Korea; consequently, a review of the existing R&D direction is required.

Therefore, this study was conducted to investigate the direction of nuclear R&D policy that the experts in the private nuclear power companies that are vulnerable to such environmental changes think of and to provide direction in the future government nuclear R&D plan. For statistical analysis, the analytical hierarchy process (AHP) methodology was applied to four major areas of nuclear technology, which are currently held or reviewed by industry, academia, and research institutes related to nuclear power. With this analysis, we aim to evaluate the 3 attributes of strategic importance, urgency, and business feasibility for each field of the nuclear power Roadmap (so called “Nu-Tech2030”, announced by the Korean government). Finally, we aim to conduct a relative importance assessment in the nuclear power R&D field through the AHP.

2. Study background

2.1. Global nuclear power plant operation policy

In the 2000s, the nuclear industry was globally recognized as a practical alternative in terms of economy and energy security owing to the rapid increase in electricity demand in developing countries, continuous rise in oil prices, and global warming issues. However, after the Fukushima nuclear accident in March 2011, a transformation occurred in the world nuclear industry. After the accident, concerns regarding nuclear safety increased, and some nuclear power plants have been temporarily or permanently shut down. Shale gas and renewable energy are gaining attention as new alternatives, negatively affecting the prospect of nuclear industry. As shown in [Table 1], some countries, including existing countries with advanced nuclear power plants, are considering reducing the operation scale of or dismantling nuclear power plants. Meanwhile, some countries that do not have advanced nuclear power plants are planning to introduce new ones or review the feasibility have one. Although the safety of nuclear power plant operation is emphasized, various policies for the operation and introduction of nuclear power plant have been adopted based on the economic and political situation of each country.

2.2. Current status of domestic nuclear policy

South Korea has 24 units of nuclear power plants, which constitutes the world's sixth largest. Currently, the domestic nuclear policy is implemented by considering the strengthening safety and the enhancement of industrial competitiveness through the opinions of experts from various sectors and the general public. The recently established “Fifth Nuclear Energy Promotion Plan” proposes directions for the promotion and use of nuclear energy from 2017 to 2021 [3]. The main contents include fulfilling greenhouse gas reduction targets and responding to climate change through nuclear power plants and establishing a management plan for spent fuel. The main feature of this plan is that first, it aims to reflect the public's interests as much as possible in relation to strengthening nuclear safety and to establish a plan through collecting opinions on nuclear safety and radioactive waste management. Another aim of the plan is to expand overseas exports by improving the nuclear technology competitiveness of South Korea and expanding nuclear-based technologies by fostering the industrial utilization of radiation.

2.3. Trend of R&D changes of major countries operating nuclear power plants (in South Korea and abroad)

As described above, the nuclear power R&D strategy of industry powerhouses is changing in accordance with the trend of domestic and foreign policy changes. The United States and France, which are the first and second largest nuclear power producers, respectively, are conducting R&D on safe and economical nuclear power plants; furthermore, they are currently developing 3.5th-generation nuclear power plants that are more economical than the latest third generation nuclear power plants. In addition, the adoption of passive safety technology is being considered for further safety strengthening.

Korea is driving R&D to strengthen the competitiveness of the nuclear industry by establishing a nuclear industry R&D roadmap [4]. In particular, the maintenance of a nuclear power plant ecosystem has emerged as the most pressing issue to cope with changes in reduced nuclear energy proportions, such as the cancellation of new nuclear power plant construction plans and the expiration of design life since the announcement of the energy transition policy by Moon Jae-in's administration in May 2017. As the government's energy transition has increased the future uncertainty of the nuclear industry, various discussions have been held regarding the roadmap for nuclear technology development, led by the Ministry of Trade, Industry, and Energy and the Ministry of Science and ICT [Table 2]. These discussions are summarized in [Table 2].

As shown in [Table 2], the Ministry of Trade, Industry, and Energy in Korea is pursuing a commercialization technology development project (nuclear key technology development project) to secure the utilization of current nuclear technology, and the Ministry of Science and ICT's original technology development project (nuclear technology development project) plans to establish a mid-to long-term roadmap. In the past two decades, 1.162 and 3531 trillion won have been invested in the abovementioned two projects, respectively, to improve the safety of nuclear power plants

Table 1
Countries by nuclear power plant policy.

Type of countries	Nuclear policy	Countries
Countries already operating nuclear power plants (31 countries)	Maintaining current status or expansion	26 countries (USA, China, Japan, UK, France, Russia, India, Canada, Sweden, South Africa, Finland, Bulgaria, Mexico, Hungary, Pakistan, Czech, Armenia, Brazil, Iran, Netherlands, Romania, Slovenia, Ukraine)
	Reduction and shutdown (Under review)	5 countries (Germany, Switzerland, Taiwan, Belgium, Korea)
Countries considering the operation of nuclear power plants (17 countries)	Reviewing the introduction	12 countries (Bangladesh, Belarus, Egypt, Indonesia, Israel, Kazakhstan, Jordan, Lithuania, Poland, Thailand, Turkey, UAE)
	Newly reviewing the introduction	2 countries (Chile, Saudi Arabia)
	Halted the introduction	3 countries (Vietnam, Venezuela, Malaysia)

※Source: See World Nuclear Power Market Insight [2].

Table 2
Key areas of discussion regarding the Nuclear Industry R&D roadmap.

Category	Key areas of discussion matters
Strengthening of safety	R&D support for essential equipment (parts, facilities, etc.) for the safe operation of nuclear power plants
Decommissioning of nuclear power plants	Development of commercialization technology for the safe and economic dismantling of permanent shut-down power plants
Radioactive waste management	Development of core technologies for safe management of radioactive wastes, such as spent fuel generated through decommissioning
Strengthening industrial competitiveness	Development of future nuclear technology fields by improving export competitiveness of nuclear power plants and equipment

and secure future nuclear technologies. It is evident that the R&D trend of nuclear power plants worldwide is primarily focused on the safe and economic operation of nuclear power plants.

3. Study overview

3.1. Study methodology: AHP

This study aims to analyze the opinions of selected experts in the field of nuclear energy, rather than the survey of a general, unspecified public. Accordingly, by applying the AHP, which enables the relative importance to be assessed through relative comparisons of factors constituting decision making, as one of the multicriteria decision-making techniques, we aim to analyze the importance of nuclear R&D promotion and business facilitation factors from the perspective of private nuclear power companies. AHP is one of the multicriteria decision-making techniques developed by Saaty in 1986, which is a decision-making methodology that can comprehensively consider the importance of each attribute constituting the decision and comparison between alternatives [5]. The relative importance between attributes that constitute the decision-making hierarchy is achieved through pairwise comparison. Ultimately, the methodology is suitable for strategic decision making, as it allows prioritization among alternatives at the lowest level. The results of this AHP analysis were used to derive the R&D priorities of private nuclear power companies, and each major discussion area regarding nuclear R&D are expected to be utilized in the future to develop a model for a nuclear energy R&D ecosystem centered on private consumers.

3.2. Study participants

Owing to the government's energy transition policy, the nuclear industry is experiencing a major change, and the target directly affected by this change is believed to be private nuclear power companies. For a long time, the domestic nuclear policy has been a unilateral policy led by the public sector with reliable power supply capacity as the top priority. However, to effectively respond to environmental changes in the nuclear industry, it is necessary to analyze and reflect the opinions of private nuclear power companies, not merely implementing R&D policies led by public sectors. In this study, private nuclear power companies are the companies established for commercial purposes other than public institutions, and an analysis was conducted on nuclear power experts working for the company. The 55 experts surveyed were selected owing to their experience in national research projects and over 15 years of experience in nuclear energy. The criteria for classifying and managing nuclear technology were based on the national science and technology classification system, which were classified into 11 medium categories and 73 minor categories. Herein, by referring to relevant technology fields, the national nuclear policy and technology level are comprehensively considered and reclassified into four major fields, as shown in [Table 2].

4. Analysis results

4.1. Survey overview

The purpose of this survey is to determine the importance of setting a priority in projects for nuclear power R&D in South Korea centered on private nuclear power companies. As described above, various studies have been conducted using the AHP because it can comprehensively assess the importance of decision-making factors relatively easily. In the study of J.M. Hong pertaining to the energy field, the weight of each decision-making factor with regard to the business feasibility evaluation criteria for the decision making of private companies for the introduction of renewable energy has been derived [6]. However, studies that analyze the importance of R&D through the application of AHP are few, except for a research by H. Chang et al. regarding nuclear power. To differentiate from the existing study, a survey was conducted on experts in private nuclear power companies conducting national nuclear R&D projects, and the 3 attributes of strategic importance, urgency, and feasibility of items were analyzed to derive the priority of nuclear R&D from the perspective of private companies [7]. Therefore, the survey areas were classified into nuclear safety, decommissioning, radioactive waste, and competitiveness strengthening.

The total number of experts surveyed was 55, and the survey period lasted from April 29 to May 3. Prior to the survey, the purpose and method of the survey were explained to the participants, and the latter were asked to fill out a questionnaire through a face-to-face interview or by e-mail. The questionnaire contents were re-explained and repeated when inquired, thereby increasing the value of the consistency index.

4.2. AHP application

The AHP is used to determine a priority when multiple items for evaluation exist. Therefore, the various alternatives to be discussed in relation to the analysis objectives were categorized into hierarchies and classified into global and local factors according to the criteria. The method of comparing two groups each for local factors is called pairwise comparison; a pairwise comparison matrix was prepared and a consistency test was performed. If the result indicates consistency, then an additional analysis is performed by considering the relative weights comprehensively.

The decision-making method using the AHP is categorized into the group and numerical integration methods, as shown in [Table 3]. In this study, the numerical integration method was applied (see Table 4).

In the numerical integration method, the geometric mean was obtained for the evaluator's evaluation results for each element of the

Table 3
AHP decision-making method.

Category	Description	Whether to study
Group integration method	A method of creating a single pairwise comparison matrix by discussing and voting between the opinions of evaluators. This is an unrealistic method requiring much time and effort.	X
Numerical integration method	A method of calculating weights by collecting each pairwise comparison matrix performed by group members and numerically integrating the evaluation values of the entire group.	O

Table 4
Random Index (RI) values.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

pairwise comparison matrix prepared based on the questionnaire filled out by the evaluator and then numerically integrated to form a single pairwise comparison matrix.

η: Total Evaluators, a_{ij}: Elements in a binoculars evaluated by the kth evaluator

Subsequently, a weight vector was derived by calculating the w matrix satisfying the following equation. By applying the weight obtained, the geometric mean of the pairwise comparison matrix was applied.

$\lambda_{\max}$: Largest eigenvalue of matrix A'

The response consistency can be verified using $\lambda_{\max}$. The consistency index (CI) can be obtained as follows:

$$(CI) = \frac{(\lambda_{\max} - n)}{n - 1}$$

Furthermore, for the random index (RI), numbers from 1 to 9 were arbitrarily set, an inverse matrix was created, and the mean consistency index of this matrix was calculated.

In the table above, n is the number of items used for pairwise comparison. The consistency rate (CR) is expressed as follows:

$$(CR) = \left(\frac{CI}{RI}\right) \times 100\%$$

In general, a response with a CR value of 10% or less is considered to ensure consistency, and a response with a CR value of 20% or less is occasionally included in the analysis. In this study, the CI value derived was 0.0004, and the calculated CR value was 0.013%; hence, consistency was assured.

4.3. Analysis result

In the definition of each evaluation item, “importance” is the extent of applicability to safety, security, and response to exclusively supplied products, “urgency” is the degree of how a skill is evaluated as urgent within a period of 10 years with a cycle of 3 years, and “business feasibility” indicates if the feasibility is 30% or less or 60% or higher in terms of the level of technical maturity. The results of the survey evaluation are shown in [Table 5] as follows.

The four key areas subject to the survey were selected in the Nuclear Industry R&D roadmap (Nu-tech 2030). A survey analysis using AHP showed similar levels of results in all four areas. These results show that Nuclear Industry R&D roadmap (Nu-tech2030) is appropriate policy for the nuclear industry. Detailed analyses of each of the three areas (Importance, Urgency, and Business Feasibility) are as follows.

As shown in [Fig. 1], the evaluation of “importance” for each of the nuclear roadmap fields showed that the highest importance was derived for the nuclear radioactive waste field, but the “strengthening of safety” field had the lowest importance. In addition, the “radioactive waste management” and “strengthening industrial competitiveness”' fields were classified under relatively high importance, and the “strengthening of safety” and “decommissioning” fields were classified under relatively low importance. This result reflects the significant importance of the field, in which revenue can be generated directly from the perspective of private nuclear power companies.

As shown in [Fig. 2], the evaluation of “urgency” for each of the nuclear roadmap fields showed that the highest urgency was derived for the nuclear “radioactive waste management” field, but the “strengthening of safety” field had the lowest urgency. In addition, the “radioactive waste management,” “decommissioning,” and “strengthening industrial competitiveness” fields were classified under relatively high urgency, and the “strengthening of safety” field under relatively low importance. However, the difference in urgency for each field did not vary significantly. Although the urgency of individual technologies differed in terms of government policy establishment, the result did not show a significant difference in urgency from the perspective of consumers and private nuclear power companies when the overall R&D fields were considered.

As shown in [Fig. 3], the evaluation “business feasibility” for each of the nuclear roadmap fields showed a clear difference from

Table 5
Results of survey responses.

category	Strengthening of safety	Radioactive waste management	Decommissioning	Strengthening industrial competitiveness
Importance	2.070	2.434	2.133	2.344
Urgency	1.973	2.398	2.323	2.294
Business feasibility	1.897	2.023	2.077	2.254
Total considering AHP (Item-weighted mean)	2.009	2.332	2.162	2.313

*Evaluated as 1(Low)-2(Average)-3(High).

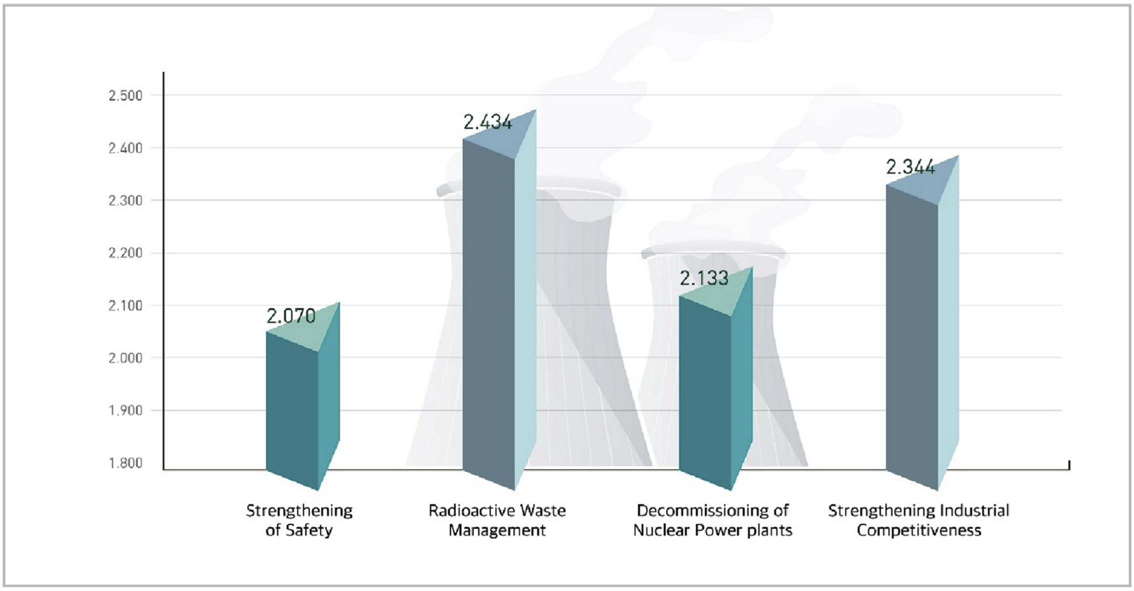

Figure 1. Evaluation of "Importance" for each field of nuclear power roadmap.

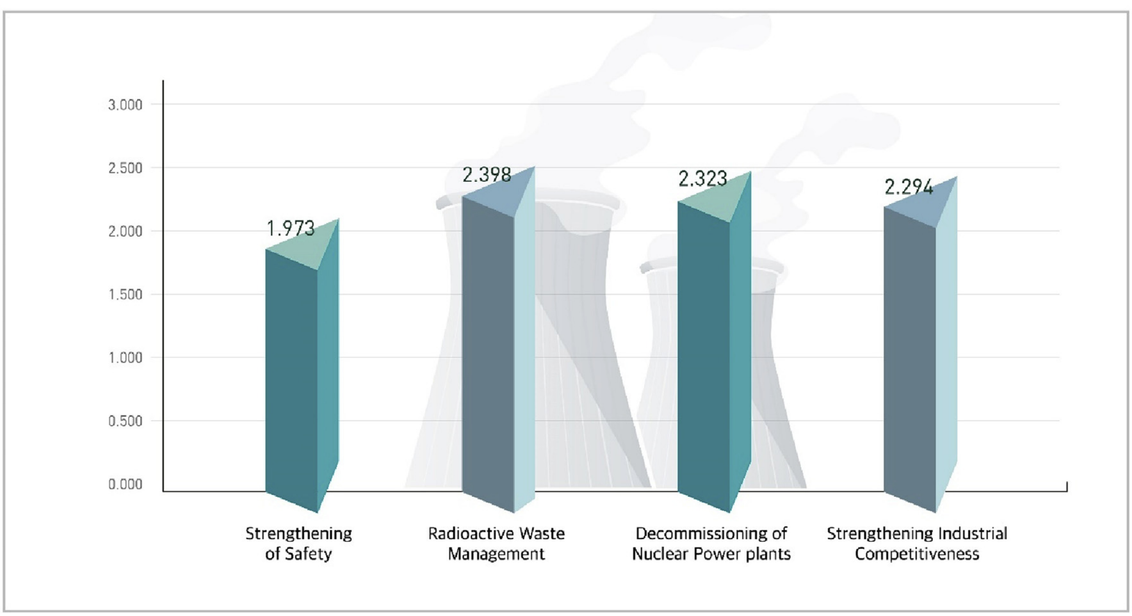

Fig. 2. Evaluation of "urgency" for each field in the nuclear power roadmap.

the findings of the trend in the importance and urgency. The highest feasibility was derived for the "strengthening industrial competitiveness" field, but the "strengthening of safety" field had the lowest feasibility. The "strengthening industrial competitiveness" field was classified under very high potential for commercialization from the perspective of the private nuclear power companies, the "radioactive waste management" and "decommissioning" fields were under the medium level group, and the "strengthening of safety" field was under the low commercialization potential group. It was interesting that the urgency evaluation showed that the difference between each field was insignificant, whereas for the business feasibility evaluation, the difference between each field was clear. This was assumed to occur because the R&D of the private nuclear power companies focused on commercialization.

The results of the relative importance evaluation through AHP analysis are presented in [Fig. 4]; they were evaluated in terms of the importance, business feasibility, and urgency, of which the values were 55.2%, 23.0%, and 21.8%, respectively. The strategic importance of the "radioactive waste management"' field was the highest, whereas that of the "strengthening of safety" field was the lowest. Results of R&D demands for private nuclear power companies showed that the demand was higher for technology development targeting new markets and new fields that can generate revenue compared with the "strengthening of safety" field emphasized by the government.

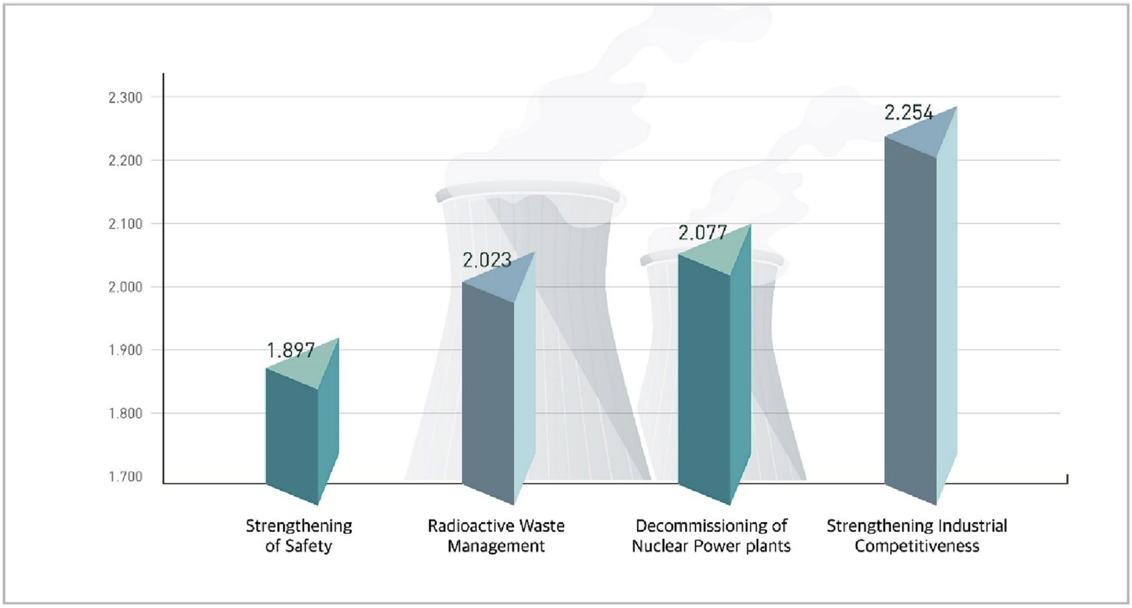

Fig. 3. Evaluation of “business feasibility” for each field of the nuclear power roadmap.

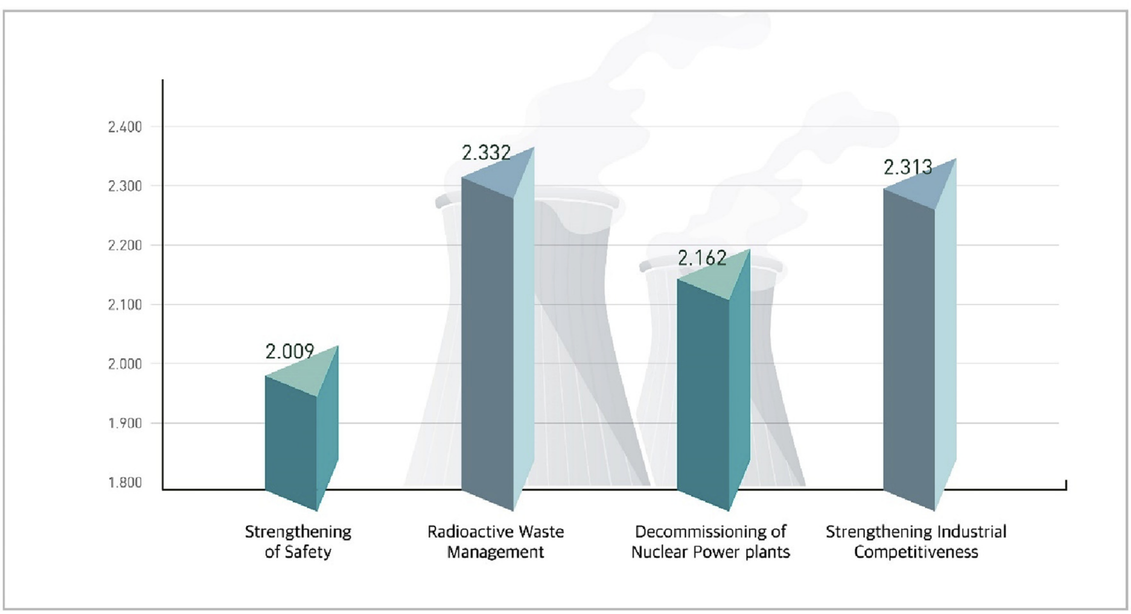

Fig. 4. AHP comprehensive analysis results (relative importance).

5. Conclusions and implications

Based on the AHP analysis of experts belonging to private nuclear power companies, technologies in the nuclear safety field showed low importance, whereas urgency and business potential showed average importance. In general, the relative importance of the AHP was evaluated to be the lowest. This is an R&D field that the current government is pursuing with the highest priority in consideration of the public's sentiment on nuclear safety; however, the investment has been biased toward safety enhancement technology primarily led by public institutions. Meanwhile, from the perspective of private nuclear power companies, this field has a relatively low probability of securing profitability in the near future and may only increase the burden on companies with high technology development investment in the long term.

Meanwhile, technologies in radioactive waste management showed high importance and urgency on average, low commercialization potential, and ranked the highest in terms of AHP relative importance. Nuclear energy must secure the original technology based on long-term investment; it is clear that the interest of private nuclear power companies is the highest in this field through government-led technology development. In the future, when discussing the technology development roadmap of the virtuous cycle of the nuclear industry ecosystem, this field is considered to be one that the government must invest continuously in technology development.

Technologies in the field of decommissioning showed high urgency and relatively low importance and business feasibility, whereas the relative importance of the AHP was evaluated to be low. As shut-down nuclear power plants increase due to the expiration of the design life of nuclear power plants, the possibility of entering the global market in the decommissioning field is regarded as relatively high. From the perspective of private companies, decommissioning technology is regarded as a field where technology commercialization is possible through short-term R&D.

Finally, technologies in the field of strengthening industrial competitiveness of nuclear power plants showed high importance, whereas urgency and business feasibility showed average importance. Meanwhile, the relative importance of the AHP was high. Private nuclear power companies, currently undergoing a slow down because of the lack of revenue-generating projects owing to the government's energy transition policy, require a breakthrough, which reflects their expectations for increased sales through overseas expansion.

In this study, an analysis was conducted to derive the future direction for nuclear R&D from the perspective of private nuclear power companies considering the nuclear environment diversifying from the existing government-led nuclear R&D direction. To reflect and implement the demand of these private companies to the nuclear industry, additional comprehensive review in the public domain is required based on the results of this study. Furthermore, as the domestic nuclear power plant ecosystem is inactive, the findings in this study will serve as basic data for discovering new businesses and effectively distributing national R&D resources, especially in consideration of the technological development demands of private companies in sectors vulnerable to these difficult environments.

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