Nuclear Engineering and Technology 54 (2022) 4809–4818

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Technical Notes

Classification and consideration for the risk management in the planning phase of NPP decommissioning project

Gi-Lim Kim, Hyein Kim, Hyung-Woo Seo*, Ji-Hwan Yu, Jin-Won Son

Korea Hydro & Nuclear Power (KHNP) Central Research Institute, 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, 34101, Republic of Korea

ARTICLE INFO

Article history:
Received 29 March 2022
Received in revised form
4 July 2022
Accepted 30 July 2022
Available online 3 August 2022

Keywords:
Decommissioning
Risk management
PMBOK
Risk matrix
Decommissioning project

ABSTRACT

The decommissioning project of a nuclear facility is a large-scale process that is expected to take about 15 years or longer. The range of risks to be considered is large and complex, then, it is expected that various risks will arise in decision-making by area during the project. Therefore, in this study, the risk family derived from the Decommissioning Risk Management (DRiMa) project was reconstructed into a decommissioning project risk profile suitable for the Kori Unit 1. Two criteria of uncertainty and importance are considered in order to prioritize the selected 26 risks of decommissioning project. The uncertainty is scored according to the relevant laws and decommissioning plan preparation guidelines, and the project importance is scored according to the degree to which it primarily affects the triple constraints of the project. The results of risks are divided into high, medium, and low. Among them, 10 risks are identified as medium level and 16 risks are identified as low level. 10 risks, which are medium levels, are classified in five categories: End state of decommissioning project, Management of waste and materials, Decommissioning strategy and technology, Legal and regulatory framework, and Safety. This study is a preliminary assessment of the risk of the decommissioning project that could be considered in the preparation stage. Therefore, we expect that the project risks considered in this study can be used as an initial data for reevaluation by reflecting the detail project progress in future studies.

1. Introduction

The decommissioning on the Nuclear Safety Act (NSA) [1] refers to "All activities done by a licensee under NSA to be exempt from the application of this Act by dismantling facilities and sites, or by removing radioactive contamination after permanent shutdown of the operation." As of December 31, 2019, a total of 26 Nuclear Power Plants (NPPs) were operated in Korea, of which Kori Unit 1 and Wolsong Unit 1 were permanently shut down in 2017 and 2019, respectively [2]. The decommissioning policy has been carried out since 2015 following the decision to permanent shutdown of Kori Unit 1, and a pan-government strategy was established in 2019. For some regulations regarding to the commercial NPP decommissioning, based on the IAEA safety requirements, starting with the 2015 Nuclear Safety and Security Commission (NSSC) Notice No. 2015-8, they have been gradually materialized [3]. In the case of the Kori Unit 1 decommissioning project, the first commercial reactor in Korea, the laws and regulations were established in such a way that specialized domestic companies with technical and engineering capabilities would participate under the general management of Korea Hydro & Nuclear Power (KHNP).

The decommissioning project of a nuclear facility is a large-scale process that is expected to take about 15 years or longer. The range of risks to be considered is also large and complex, as comprehensive engineering and convergence technology that combines knowledge and technology in various fields such as mechanical, electrical, chemical, and civil engineering as well as radiation safety management is applied. In addition, it is expected that various risks will arise in decision-making by area during the project. For successful project management of the Kori Unit 1 which is still in the preparatory phase, it will be necessary to conduct a risk assessment for the identified risks by reflecting the domestic laws and regulations and preparations for decommissioning licensing.

Domestically, there were lots of studies on project risk management of NPP construction, while there were no studies on whole project risk management of NPP decommissioning. However, in some areas of project elements, such as the safety evaluation, core technologies, and legal factors, the risks expected in the relevant field are evaluated and managed [3,4]. Internationally, IAEA SRS

* Corresponding author.
E-mail address: sehywo1727@khnp.co.kr (H.-W. Seo).

https://doi.org/10.1016/j.net.2022.07.022

No.97 presents a recommended risk management methodology for the strategy and execution stage of the nuclear facility decommissioning through the Decommissioning Risk Management (DRiMa) project conducted between 2012 and 2015 [5].

Therefore, in this study, the risk family derived from the DRiMa project was reconstructed into a decommissioning project risk profile suitable for the Kori Unit 1 in order to check whether the risk management system for the domestic decommissioning project was properly prepared. The risk family was identified as the risk of the decommissioning project, and the background and various requirements of the domestic decommissioning project were used to analyze whether risks could be managed. To do this, the contents considered in the relevant domestic legislations, the NSSC notices, the decommissioning plan and the regulatory guidelines were utilized. In the case of the decommissioning plan, there are no approved licensing documents other than the Initial Decommissioning Plan (IDP). Therefore, the technical guidelines of laws and regulations were used as a basis and supplemented with domestic decommissioning-related papers and overseas cases. Based on this analysis, a comparison table by risk breakdown structure and risk assessment results for domestic decommissioning project were derived, and considerations were prepared according to the results.

2. Review of relevant literature for risk identification

In this study, for risk identification based on the risk management theory of Project Management Body of Knowledge (PMBOK) issued by PMI in the U.S. [6], the 15 requirements of the IAEA GSR Part 6 [7] that became the baseline when establishing domestic decommissioning regulations, and the decommissioning project risk family suggested by the DRiMa project [5] were reviewed and risk matrix standards were established. Through this, it was qualitatively evaluated for each risk whether the decommissioning project of Kori Unit 1 was reflected or not. To determine the priority of applying the risk matrix, the contents of relevant domestic laws, the NSSC notices, the decommissioning plan and regulatory guidelines were used.

2.1. PMBOK and risk management

PMBOK defines a project as a temporary effort to create a unique product, service, or result. The project management system consists of process groups and knowledge areas, and both of them are interconnected [6]. A process is a series of systematic activities that produce one or more outputs with one or more inputs, resulting in final results [6]. During the project, unplanned events or failures may occur, which may result in unexpected losses (i.e. delays or cost overruns). This is described as a risk, and the risk is defined as an uncertain event or condition that positively or negatively affects one or more project goals when it occurs [6].

If executives highly pay attention to project risk, it could be more successful to achieve their goal, and more valuable to improve the project risk management system [8]. PMBOK's risk management knowledge area, as shown in Fig. 1, includes 7 processes – Plan risk management, Identify risks, Perform qualitative risk analysis, Perform quantitative risk analysis, Plan risk responses, Implement risk responses, and Risk monitoring. Most of them are carried out at the planning stage of the project. In general, a risk can be recognized as a safety risk, but in this study, we assumed that a safety is one of the requirements for decommissioning project activities, so the safety was considered as one category of the project risk [5].

2.2. Safety requirements of IAEA and relevant laws in Korea for the decommissioning

When decommissioning a domestic commercial reactor, the requirement for the project is to remove facilities and sites from the regulation of the NSA. Therefore, nuclear safety laws and regulatory requirements affect decommissioning design, planning, and project activities. In addition, many provisions of the laws apply equally not only during construction or operation but also during decommissioning.

The domestic laws and regulatory requirements for decommissioning reflect requirements related to the safe decommissioning of nuclear-related facilities presented in GSR Part 6, published by the IAEA in 2014. Accordingly, Table 1 shows the major licensing documents related to decommissioning that must be approved before the start of the decommissioning or submitted during the decommissioning in Korea.

3. Risk breakdown structure of DRiMa project and reflections of Kori-1 decommissioning

In Korea, KHNP is the only-licensed owner of commercial NPPs, and also KHNP performs both the operation and decommissioning. It is different from the other countries where the owner of the operation and the decommissioning is different. Accordingly, interfaces with contractors in domestic decommissioning project is appropriate to consist of sub-items of organization and human resources. Therefore, in this chapter, the 10 categories of risk family suggested by the IAEA were reorganized into 9 categories according to the domestic decommissioning plan and related regulatory requirements. In the case of risk, there is an aspect that one event is linked to the risk of another event, but in the scope of this study, only the primary events occurring in the prompts for each category were considered.

3.1. Initial condition of facility

The risk composition related to the initial condition of facility includes (1) Physical status, (2) Radiological status and characterization, (3) Status of waste and materials, and (4) Site characteristics. The NSSC announces that the condition of the decommissioning facilities should be considered from the IDP stage to the FDP stage. Also, it should be revised every 10 years. If essential information of the initial facility is not verified at the time of decommissioning, it may act as a prompt for unexpected events in the process of decommissioning execution. The physical status has prompts such as operational history and records, list of SSCs and their physical status. The radiological status and characterization have prompts such as contamination or activation of SSCs, contamination of soil and underground water. The key record or operation history necessary for the decommissioning may be insufficient if those are not publicly notified by laws and regulations before the construction of NPP. It would be considered as a major risk of the decommissioning project. The status of waste and materials has prompts such as spent fuel, operational waste, and hazardous materials. The site characteristics has prompts such as interdependencies with other facilities, site infrastructure, site environmental characteristics, and structural arrangement in facilities and buildings.

3.2. End state of decommissioning project

The risk composition related to the end state of decommissioning project includes (1) Definition of the end state of the project and (2) Difficulty in achieving the end state. The NSSC

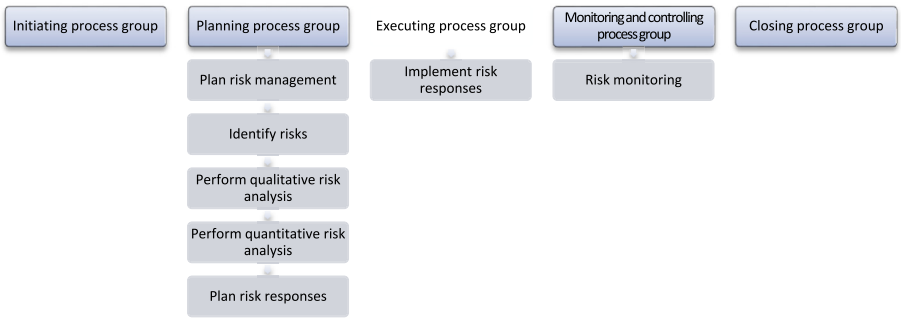

Fig. 1. Risk Management Process [6].

Table 1
Decommissioning license documents and scope of preparation [9–11].

Period	Licensing documents	Scope
Permission for construction and operation	Initial Decommissioning Plan (IDP)	• Overview of the decommissioning plan • Project management • Site and environment status • Strategies and methods for decommissioning • Design characteristics and action plan for decommissioning availability • Safety assessment • Radiation protection • Decontamination and dismantlement activity • Radioactive waste management • Environmental impact assessment • Fire protection • Reference • Appendix: Definitions
Within 5 years of shutdown	Final Decommissioning Plan (FDP)	• Overview of the decommissioning plan • Project management • Site and environment status • Strategies and methods for decommissioning • Design characteristics and action plan for decommissioning availability • Safety assessment • Radiation protection • Decontamination and dismantlement activity • Radioactive waste management • Environmental impact assessment • Fire protection • Other things to note • Reference • Appendix: Definitions
Every half of the year after the commencement of decommissioning	Decommissioning Status Report	• Decontamination activities • Dismantling activities • Radiation protection • Environmental radiation safety protection • Radioactive waste management • Fire protection • Quality assurance
When the decommissioning was completed	Decommissioning Completion Report/Final Site Status Report	• Decommissioning strategy and progress • Facilities and site status before and after decommissioning • Status of final radiation, radioactivity and radioactive waste management at facilities and sites • Radiation dose of workers participated in decommissioning • Abnormal events that occurred during the decommissioning • Survey plans, methods, and results on the radiation and radioactivity of the final site status • Future plan of site reuse

notices and regulatory guidelines require the FDP to present the reuse plan of residual buildings and residual radioactivity (radiological targets) for facilities and sites [12]. The definition of the end state of the project has prompts for buildings, facility, and site. In Korea, matters related to the end state are clearly described under the NSA. When it is recognized that the decommissioning has been completed, the contractor is notified of the termination of the permission for operation in writing, and the facility and site are released from the regulation of the NSA [9]. Conformity with the approved decommissioning plan will be determined through the decommissioning completion report and the final site status report at the time of decommissioning completion [13]. It is believed that matters related to the difficulty in achieving the end state will be evaluated through the management of projects by the licensee. In addition, since the requirements for site release and reuse of facility and site are related to residents' acceptance and the local economy, consultation with interested parties could affect the difficulty in achieving the end state [14].

3.3. Management of waste and materials during the decommissioning

Risks related to management of waste and materials include (1) Waste management policy, (2) Waste estimation and characterization, and (3) Waste management infrastructure. Waste management policy has prompts for site release criteria, clearance levels, and waste acceptance criteria, and prompts related to waste management infrastructure include treatment facilities, storage facilities, disposal facilities, and transport. In Korea, KHNP plans to build waste treatment facilities and equipment to dispose of waste generated during the decommissioning NPPs [2]. The owner of a radioactive waste disposal facility, Korea Radioactive Waste Agency (KORAD), establishes an annual radioactive waste management implementation plan. In 2021, KORAD plans to develop containers and establish specific acceptance criteria for various types of radioactive waste, including chemicals (hazardous materials, etc.), and consult with regulatory authority [15]. If communication between decommissioning licensee and waste management agency is carried out smoothly in terms of acceptance and disposal, the probability of negative risks can be greatly reduced. Prompts related to waste estimation and characterization include operational waste, decommissioning waste, and unknown waste. The generation of secondary radioactive and non-radioactive waste and the grade of radioactive waste will depend on the proper management and decontamination method of the project. Therefore, it should be managed in connection with the risks of decommissioning strategies and technologies.

3.4. Organization and human resources (stakeholders)

Risk classified to organization and human resources includes (1) Organizational structure, (2) Human resources, and (3) Relationship with contractors and procurement. In Korea, there are no options such as license transfer or asset sales. The project management approach for contract and procurement will be similar to outage period during operation. Therefore, we considered that the risks from interfaces with contractors and suppliers are not relatively significant. In this study, the two risk categories (organizational and human resources, communication with contractors and suppliers) presented in the DRiMa project were considered as stakeholders within the project and integrated into one. The NSSC notices and regulatory guidelines mainly deal with these contents in the field of project management.

Projects may not always be carried out as originally planned. Accordingly, tasks should be allocated, organized, and reorganized to actively prepare for risks [8]. Prompts related to human resources include technology, knowledge, education and training, human factors and mind-set, safety culture, and communication. Since the environment of the decommissioning project is different from the normal operation surroundings of the NPP, organizations participating in the decommissioning project should adapt to the new circumstances and goals [16]. The prompts related to the relationship with the contractor and procurement include contractual strategies, procurement processes and contractor selection, the contractor interface and integration within the project. In connection with the national policy, KHNP established a strategy to carry out decontamination, dismantling, and site restoration work that requires expertise through a domestic specialized company when decommissioning the Kori Unit 1. Domestic industries have no experience in decommissioning commercial reactor, but they have the technology and experiences necessary for decommissioning from the replacement of large component during operational phase of NPPs [2].

3.5. Finance

Risks related to finance include (1) Cost and (2) Funding (provisions). According to the NSA, the Radioactive Waste Management Act, and the Ministry of Trade, Industry and Energy (MOTIE) Notice, the decommissioning plan should describe matters related to securing costs and funding sources in the project management field. The prompt related to the cost includes cost estimation, and the prompts related to the funding are funding sources, funding mechanisms (procurement process), and financial governance. According to Article 12 of MOTIE Notice No. 2022-11 (Regulations on the Calculation Standards for Radioactive Waste Management Costs and Spent Fuel Management Charges, Jan. 11, 2022), the cost of decommissioning as of the end of 2020 was KRW 872.6 billion per unit. It is judged that the scope of uncertainty can be reduced or controlled within the allowable range if the experiences, lessons learned and reference obtained from previous decommissioning projects are reflected.

3.6. Decommissioning strategy and technology

The detailed risks of the strategy and technology presented in the DRiMa project are (1) Decommissioning strategy, (2) Decommissioning scenarios, and (3) Technology. In Korea, since a system for integrated management of decommissioning is under development, we added (4) Project management as a risk of strategy and technology. The NSSC notices and regulatory guidelines mainly focus on schedule and integrated management in the field of decommissioning strategies and methods.

Prompts related to the decommissioning strategy include immediate dismantling, deferred dismantling, and combination of two methods. In the case of Kori Unit 1, an immediate dismantling strategy was selected in line with the national policy established in 2015 [2]. Prompts related to the decommissioning scenarios include technical feasibility and alternative scenarios. Risk management considering these factors is not included in the scope of the decommissioning plan according to the NSSC notices. However, if an appropriate management system is established that allows detailed plan changes affecting the project are reflected in a timely manner, uncertainty could be reduced and the project success rate would be increased. Prompts related to technology are availability, maturity, research, development, and demonstration. According to the FDP review guidelines, technical feasibility and field applicability should be presented in the decommissioning method to manage technology-related risks. In addition, as described in 3.4, it was identified that domestic industries possess various technologies and experiences required for decommissioning.

3.7. Legal and regulatory framework

The composition of risks related to legal and regulatory framework is (1) Laws and regulations, and (2) Licensing process. Decommissioning-related laws and regulatory systems have been prepared, suggesting the roles of the government, regulatory agencies, and operators for decommissioning.

Prompts related to laws and regulations include gaps in regulation, inconsistencies in regulation, and potential legal and regulatory changes. The decommissioning regulatory requirements, project performance requirements, technical requirements, and standards have a complex interrelationship. The prompts associated with the licensing process are the complexity of the licensing processes and uncertainty of regulatory review (result and timing). The results of the risk of uncertainty in regulatory review are as follows: Policies related to spent fuel which must be established at the national level, or delays in projects due to issues that may arise

if consultations with other organizations are preceded.

In addition, the licensee should not contain unnecessary details so as not to go through a complicated revision procedure again [17]. In accordance with Article 28 of the NSA and Article 23-2 of the Enforcement Rule of the NSA, the licensee must report the semi-annual decommissioning status of the facility and the results of the decommissioning completion to the NSSC. However, there might be changes in related laws and regulations in long-term decommissioning project. Accordingly, there is a possibility that the confirmation and inspection focus could also be changed. Therefore, the owner of decommissioning project must prepare information in consideration of the scope to which it can respond.

3.8. Safety

Safety risks include (1) Radiological safety, (2) Non-radiological safety, (3) Safety of adjacent unit, and (4) Security. In a decommissioning project, safety risks greatly affect the success of the project. Although safety assessment can be managed with the same methodology as risk management, risk management focuses on risk management to support the achievement of project objectives, and safety assessment focuses on demonstrating that decommissioning operations are performed safely. Therefore, it is necessary to distinguish the two processes within a project [5]. The NSSC notices and regulatory guidelines specify that most of the decommissioning plans should be made with safety in mind.

In the case of radiological safety, there are prompts such as radiation protection of workers, radiation safety of the public, and radiological effluents into the environment. In this regard, relative laws and NSSC notices regulate the risks through safety assessment, radiation protection, and environmental impact assessment. However, in practice, the detailed parameters that affect the achievement of ALARA in individual tasks are distinguished from those in operation period [16]. The prompts for non-radiological safety include conventional safety of workers, impact of decommissioning activities, and impact of hazardous materials. In the case of conventional safety, the risk and correlation of radiation safety in the planning stage is unclear and complex, so it can be considered in combination [18]. The prompt for safety of adjacent unit includes the safety impact of decommissioning activities on nearby NPPs. Security prompts include security and access. In the case of a decommissioning project, laws and regulations applied in terms of security and access are not expected to change. The facilities subject to decommissioning will be affected by the NSA even if decommissioning is permitted, and the same level of security as the operating facilities will be applied.

3.9. Interested parties

Risks related to interested parties include (1) Communication and (2) Involvement of interested parties. It was not mentioned separately in the guidelines for detailed guidelines for preparing a decommissioning plan noticed by the NSSC. However, in Articles 143 to 145 of the Enforcement Decree of the NSA, provisions such as holding public hearings and collecting residents' opinions were stipulated to provide a mechanism for communication with interested parties. In addition, indirect participation (intervention) was made by reviewing the opinions derived from this and having the owner of the project reflect them in the FDP.

In the case of communication, public acceptance, transparency, and communication media are the prompts, and in the case of involvement of interested parties, consultation and engagement act as prompts. In the case of decommissioning of overseas NPPs, the participation of interested parties was carried out in various means and methods at various stages [14]. This has helped to create a positive effect by forming agreements with stakeholders in a timely manner, and to complete the decommissioning project within the planned schedule and cost range. In Korea, if a customized monitoring system for stakeholders by using existing communication methods or adding communication channels is established by referring to overseas best practices, risks related to interested parties could be appropriately managed.

4. Risks considered for the domestic decommissioning project

In the previous section, based on the risk system suggested by the DRiMa project, the expected reflection of the risk in the domestic decommissioning project was analyzed. In this process, risks that can be considered in the domestic decommissioning project were selected and classified into 9 categories. Also, in order to use the domestic reflections as a basis for evaluating the priorities of risks, the relationship between the project knowledge area, IAEA decommissioning requirements, domestic nuclear related laws and decommissioning plan preparation guidelines, etc. presented by PMBOK is shown in Table 2.

5. Prioritization of domestic decommissioning risks

In this section, two criteria of uncertainty and importance are presented in order to prioritize the selected 9 categories of decommissioning project risks. To do this, the risk management system was expressed as a score by applying the criteria (risk score table and matrix) presented in SRS No.97. Table 3 quantifies the uncertainty (U) caused by the reflection of decommissioning related laws. The closer the score is to 1, the better the law considers risks, and the closer the score is to 5, the higher the probability of occurrence of events due to uncertainty in the planning and implementation process because risks are not considered.

Table 4 shows the uncertainty score table for each risk evaluated by applying Table 3. To evaluate uncertainty, 4 aspects are considered: (A) the relevant laws and administrative rules, (B) regulatory institute review guidelines, (C) IDP preparation guidelines, and (D) FDP preparation guidelines. For each risk, 1 to 5 points are given by applying criteria as shown in Table 3. The average value of 4 aspects was used as the uncertainty of the risk. The uncertainty score is the lower the level of application, the higher the score.

The decommissioning project manager must achieve the project goal (quality) while balancing the triple constraints of the project: schedule, scope, and cost [19]. Therefore, when an event occurs due to a risk, the project importance (I) is scored according to the degree to which it primarily affects the schedule, cost, scope, quality, and the factor considered in the decommissioning status report and the decommissioning completion report as shown in Table 5. As the importance score is closer to 1, the occurrence of risk-induced events has little effect on the triple constraints or is hardly considered in terms of decommissioning status reporting and decommissioning completion. On the other hand, the closer the score is to 5, the greater the impact of risk-induced events on the triple constraints or the case is carefully considered at the time of decommissioning status report and decommissioning completion.

Table 6 shows the importance score table for each risk evaluated by applying the criteria in Table 5. If the risk does not consider all factors, 1 point was given, and 2 points were given considering 1 factor. In addition, if the risk considers 2 factors, 4 points were given, and 5 points were given considering 3 or more factors. The initial condition of facility is considered to have a direct impact on the project scope, but it was judged that there will be no or insignificant impact in other scopes, so 2 points were given. At the end state of the decommissioning project, the difficulty of completion

Table 2
Comparison of the scope of decommissioning project risk classification system, project management system, IAEA and domestic decommissioning requirements.

Risk classification system	Project knowledge area (PMBOK)	Requirements for IAEA GSR Part 6	Requirements for domestic laws and regulations, notices and administrative rules
Initial condition of facility	Scope management	–	• Construction and operation permit application and technical details • Facility status and operation history • Records of construction and operational phases that could affect decommissioning • History of accidents and radiation leaks • Radiological characteristics • Environmental monitoring before decommissioning • Establishment of waste management plan before construction • Radioactive waste management • Site status, environmental status
End state of decommissioning project	Scope management	• Requirement 15: Completion of decommissioning actions and termination of the authorization for decommissioning	• Decommissioning completion report and inspection • Reuse plan for remaining buildings • Residual radioactivity • Decontamination target level and applicability of decommissioning of facilities and sites
Management of waste and materials	Scope management	• Requirement 14: Radioactive waste management in decommissioning	• Waste disposal restrictions and delivery standards • Self-disposal criteria • Limitation of concentration of liquid and gaseous emissions • Establishment of comprehensive management plan for decommissioning waste • Radioactive waste disposal facility • Regulations on the transport of radioactive waste
Organization and human resources	Resource management Communication management Procurement management Stakeholder management	• Requirement 6: Responsibilities of the licensee for decommissioning	• Decommissioning organization and human resources • Radiation protection organization and qualifications • Fire protection organization • Establishment of education plan for people entering radiation management area
Finance	Cost management	• Requirement 9: Financing of decommissioning	• Decommissioning costs and ways to secure financial resources • Provision (decommissioning cost) accumulation • Estimation of expected decommissioning cost
Strategy and technology, project management	Schedule management Integrated management	• Requirement 2: Graded approach in decommissioning • Requirement 6: Responsibilities of the licensee for decommissioning • Requirement 7: Integrated management system for decommissioning • Requirement 8: Selecting a decommissioning strategy • Requirement 10: Planning for decommissioning • Requirement 11: Final decommissioning plan • Requirement 12: Conduct of decommissioning actions • Requirement 13: Emergency response arrangements for decommissioning	• Establishment of decommissioning strategy from construction to decommissioning commences • Establish a specific decommissioning schedule • Establishment and implementation of decommissioning quality assurance plan • Application of technology with proven safety requirements • Decontamination activities • Environmental impact assessment • Decommissioning procedure
Legal and regulatory framework	Scope management Quality management Stakeholder management	• Requirement 4: Responsibilities of the government for decommissioning • Requirement 5: Responsibilities of the regulatory body for decommissioning	–
Safety	Quality management	• Requirement 1: Optimization of protection and safety in decommissioning • Requirement 3: Assessment of safety for decommissioning	• Operational safety measures • Radiation protection measures • Assessment and management of radiation exposure • Environmental investigation and environmental radiation monitoring • Medical examination • Decommissioning safety assessment • Standards for installation of radiation protection equipment • Protection optimization, dose limits • Radiation protection plan • Decommissioning environmental impact assessment • Fire protection • Restricted area setting, restriction of installation of hazardous facilities • Operational safety measures • Consideration of the safety impact of adjacent unit
		–	

Table 2 (*continued*)

Risk classification system	Project knowledge area (PMBOK)	Requirements for IAEA GSR Part 6	Requirements for domestic laws and regulations, notices and administrative rules
Interested party management	Communication management Stakeholder management		• Collecting and reflecting public opinions on the draft FDP • Gathering opinions on matters that are expected to cause social conflict

Table 3
Risk score according to uncertainty (reflection of decommissioning related laws) [5].

Uncertainty score (U)	Percentage	Criteria
1	0–20%	The risk-reflection degree of related laws is very high, so when the project is reflected, the probability of occurrence of an event due to risk is very low
2	21–40%	The risk-reflection degree of related laws is high, so when the project is reflected, the probability of occurrence of an event due to risk is low
3	41–60%	The risks of related laws are reflected, but when the project is reflected, the probability of occurrence of an event due to risk is exist
4	61–80%	The risk-reflection degree of related laws is low, so when the project is reflected, the probability of occurrence of an event due to risk is high
5	81–100%	The risk-reflection degree of related laws is very low, so when the project is reflected, the probability of occurrence of an event due to risk occurrence very high

Table 4
Uncertainty score evaluation result for each risk.

Decommissioning project risk classification system		A	B	C	D	Uncertainty score (U)
Initial condition of facility	Physical status	1	1	1	1	1
	Radiological status and characterization	1	1	1	1	1
	Status of waste and materials	3	2	2	2	2
	Site characteristics	3	1	3	1	2
End state of decommissioning project	Project completion (site restoration)	1	1	5	1	2
	Difficulty in achieving the end state	5	5	5	5	5
Management of waste and materials	Waste management policy	1	1	3	1	2
	Waste estimation and characterization	5	2	4	3	4
	Waste management infrastructure (on-site/off-site)	1	1	4	3	2
Organization and human resources	Organizational structure	3	3	4	3	3
	Human resources	4	4	5	4	4
	Relationship with contractors and procurement	5	5	5	5	5
Finance	Cost	1	1	2	1	1
	Funding	1	1	1	1	1
Decommissioning strategy and technology	Decommissioning strategy	1	1	2	1	1
	Decommissioning scenarios	3	3	4	3	3
	Technology	1	1	4	1	2
	Project management system	4	4	5	4	4
Legal and regulatory framework	Laws and regulations	4	4	4	4	4
	Licensing process	3	3	5	5	4
Safety	Radiological safety	1	1	2	1	1
	Conventional safety	2	1	1	1	2
	Safety of adjacent unit	3	3	5	5	4
	Security	1	4	5	5	4
Interested parties management	Communication	4	5	5	5	5
	Involvement of interested parties	2	5	5	5	4

Table 5
Risk score according to decommissioning project importance [5].

Importance score (I)	Degree	Criteria
1	0–20%	The event occurrence due to risk does not affect the scope, schedule, or cost change, or is not considered in decommissioning status report and decommissioning completion
2	21–40%	The event occurrence due to risk has little effect on the scope, schedule, or cost change, or is rarely considered in decommissioning status report and decommissioning completion
3	41–60%	The event occurrence due to risk may have some effect on the scope, schedule, or cost change, or may be considered in decommissioning status report and decommissioning completion
4	61–80%	The event occurrence due to risk affects the scope, schedule, or cost change, or is considered in decommissioning status report and decommissioning completion
5	81–100%	The event occurrence due to risk has significant effect on the scope, schedule, or cost change, or is carefully considered in decommissioning status report and decommissioning completion

was given 2 points because it is a risk that only affects the scope of the project. However, the completion is not only a risk that directly affects the scope of the project, but also an important matter to be evaluated at the time of decommissioning status report and

Table 6
Importance score evaluated for each risk.

Decommissioning project risk classification system		Factor to consider	Importance score (I)
Initial condition of facility	Physical status	• Project scope	2
	Radiological status and characterization	• Project scope	2
	Status of waste and materials	• Project scope	2
	Site characteristics	• Project scope	2
End state of decommissioning project	Project completion (site restoration)	• Project scope • Decontamination of structures and equipment, Restoration of soil, surface water and groundwater • Investigation plan, method and result on radiation and radioactivity level of the final site condition, Site reuse plan, Reactor facility and site status before and after decommissioning	5
	Difficulty in achieving the end state	• Project scope	2
Management of waste and materials	Waste management policy	• Project scope • Radioactive waste management status	4
	Waste estimation and characterization	• Project scope • Management status of liquid and gaseous radioactive waste	4
	Waste management infrastructure (on-site/off-site)	• Project scope • Temporary storage facility management	4
Organization and human resources	Organizational structure	–	1
	Human resources	–	1
	Relationship with contractors and procurement	–	1
Finance	Cost	• Project cost	2
	Funding	• Project cost	2
Decommissioning strategy and technology	Decommissioning strategy	• Project schedule • Decommissioning strategy and progress	4
	Decommissioning scenarios	• Project schedule • Decommissioning strategy and progress	4
	Technology	• Project schedule	2
	Project management system	–	1
Legal and regulatory framework	Laws and regulations	• Project scope • Project quality	4
	Licensing process	• Project scope • Project quality	4
Safety	Radiological safety	• Project quality • Air purification system, Radiation monitoring and measurement, Radiation safety management and protection activities, Environmental radiation and radioactivity management • Radiation dose of workers participating in dismantling, Final radiation and radioactivity status of reactor facilities and sites	5
	Conventional safety	• Project quality • Fire protection facilities and activities, Dismantling inspection of structures, systems, and equipment • Abnormal events that occurred during the dismantling process	5
	Safety of adjacent unit	• Project quality	2
	Security	–	1
Interested parties management	Communication	–	1
	Involvement of interested parties	–	1

decommissioning completion, so 5 points were given. In the case of waste and material management, it directly affects the scope of the project and includes matters to be reported in the semi-annual decommissioning status report, so it was calculated as 4 points. The financial field does not affect the scope or schedule of the project, but it was judged that it would have a direct impact on the cost, so 2 points were given. In the decommissioning strategy and technology and project management risk categories, 4 points were given to the decommissioning strategy and scenario, as not only the schedule but also the semi-annual progress were considered, and the decommissioning technology expected to affect only a certain part was given 2 points. The project management system was evaluated as 1 point as it has no direct influence in terms of importance. In the case of the legal and regulatory framework, 4 points were given because it is a category that directly affects the scope and quality of the project. In safety risk, radiation safety and non-radiation safety (conventional safety) were given 5 points because they are important considerations not only for project quality but also for decommissioning status report and decommissioning completion. The security part of safety risk, organization and human resources, and interested parties management did not have a direct impact on the importance factor, so it was evaluated as 1 point.

Table 7 shows the uncertainty and importance evaluation results for each risk category and the resulting risk score. The risk score was classified into high (risk score 20–25, red), medium (risk score 6–19, yellow), and low (risk score 1–5, green) according to the risk matrix in Fig. 2.

As a result, among the 26 decommissioning project risks, the risk given the highest score was the category of legal and regulating framework. This risk was considered to be the highest due to the high score in both uncertainty and importance. In this study, there was no high level risk. The risks assigned to the medium level included 10 risks, such as project completion, and the risks assigned to the low level corresponded to 16 risks, including the physical status of the initial facility.

Table 7
The risk score for the domestic NPP decommissioning.

Decommissioning project risk classification system		Uncertainty (U)	Importance (I)	Risk score = U × I
Initial condition of facility	Physical status	1	2	2
	Radiological status and characterization	1	2	2
	Status of waste and materials	2	2	4
	Site characteristics	2	2	4
End state of decommissioning project	Project completion (site restoration)	2	5	10
	Difficulty in achieving the end state	5	2	10
Management of waste and materials	Waste management policy	2	4	8
	Waste estimation and characterization	3	4	12
	Waste management infrastructure (on-site/off-site)	2	4	8
Organization and human resources	Organizational structure	3	1	3
	Human resources	4	1	4
	Relationship with contractors and procurement	5	1	5
Finance	Cost	1	2	2
	Funding	1	2	2
Decommissioning strategy and technology	Decommissioning strategy	1	4	4
	Decommissioning scenarios	3	4	12
	Technology	2	2	4
	Project management system	4	1	4
Legal and regulatory framework	Laws and regulations	4	4	16
	Licensing process	4	4	16
Safety	Radiological safety	1	5	5
	Conventional safety	2	5	10
	Safety of adjacent unit	4	2	8
	Security	4	1	4
Interested parties management	Communication	5	1	5
	Involvement of interested parties	4	1	4

The risks classified by medium level were evaluated with a score of 8–16 as shown in Table 7. In the case of project completion or waste and materials management category, it was evaluated as a medium level because its importance was highly evaluated due to the scope of the project and related documents that should be reported at the time of project completion. On the other hand, the risk of difficulty in achieving the end state and safety of adjacent unit were evaluated as a score of 10 and 8 because the uncertainty was highly evaluated. The risk of decommissioning scenarios was evaluated as a score of 12 due to the uncertainty and high level of

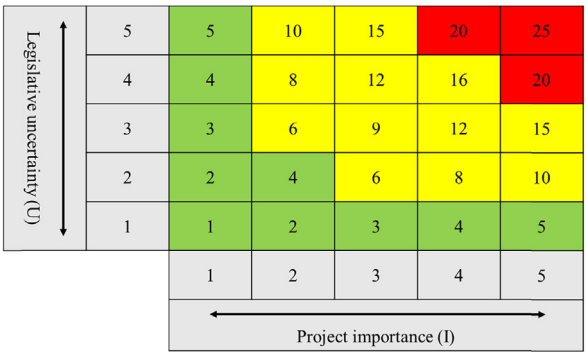

Fig. 2. Project risk matrix [5].

importance. In addition, the category of legal and regulatory framework were the highest among the medium levels because both uncertainty and importance were highly valued. Conservation safety was evaluated as a score of 10 due to the importance of safety related documents and quality of the project.

6. Conclusions

To analyze the risk of the decommissioning project of Kori Unit 1, the first commercial NPP in Korea, we reorganized the risk family derived from the DRiMa project into a decommissioning project risk profile suitable for Korea. In addition, in order to check whether the relevant risks are reflected or not, the contents considered in the relevant domestic laws and regulations, the NSSC notices, the decommissioning plan, and the regulatory guidelines were analyzed. In the case of the decommissioning plan, there is no approved document other than the IDP yet, so the technical guidelines of the notice were taken as a basis and it was supplemented with domestic decommissioning and related papers and overseas cases.

As a result, the risk score was relatively high in the domestic decommissioning environment, and it was evaluated as a category of laws and regulations (laws and regulations, licensing process), waste estimation and characterization, and decommissioning scenario risks, and it is necessary to take appropriate measures. It can be seen that the risk of the remaining categories was given a relatively low level of score compared to this. However, viewpoints on importance may be different, and depending on the project environment, if the importance factor is modified or a specific factor is weighted, the score may change. In addition, since this study considered only the primary direct impact, the possibility that a area with relatively low uncertainty or low importance will be affected by risks in other areas should not be overlooked. Appropriate monitoring and selective action are required.

Although this study reconstructed the IAEA risk list focusing on risks managed within the scope of decommissioning plans suggested by relevant laws and regulations in Korea, there is a limitation in that objective data cannot be secured in the importance evaluation process because there is no experience in decommissioning plans for commercial NPPs yet. Since the risk categories were identified through a qualitative evaluation considering the decommissioning status in Korea, it is necessary to perform risk evaluation based on actual data for each characteristic of each NPP in order to improve reliability. Although the laws and licensing procedures that must be applied to all NPPs in Korea are the same, risks will be applied differently to because the contamination state of the NPP and the given environmental and physical conditions are different. Therefore, we expect that the project risk of this study conducted in the stage of preparing for the decommissioning of nuclear facilities can be used as an initial data for reevaluation by reflecting the detailed project progress for future studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

References

[1] Nuclear Safety Act, June 2021 (In Korean).
[2] KHNP, Open nuclear power plant operation information, Korea Hydro & Nuclear Power Co., [Online]. Available: http://npp.khnp.co.kr/.
[3] KISTEP, 2020 Initial Feasibility Study Report: Nuclear Power Plant Decommissioning Core Technology Development Project, Korea Institute of S&T Evaluation and Planning, March 2021, 11-1721000-000520-01.
[4] H. Yoon, A Search for a Legal Regime for Nuclear Decommissioning in Korea - in Consideration of Fostering a Nuclear Decommissioning Industry, 2020.
[5] IAEA, Management of Project Risks in Decommissioning, International Atomic Energy Agency, 2019. SRS No.97.
[6] PMI, PMBOK Guide, Project Management Institute, 2017. Rev.6.
[7] IAEA, Decommissioning of Facilities, International Atomic Energy Agency, 2014.
[8] T. Raz, et al., Risk Management, Project Success, and Technological Uncertainty, November 2002.
[9] Enforcement Rule of the Nuclear Safety Act, June 2021 (In Korean).
[10] NSSC, Standard Format and Content of the Decommissioning Plan for Nuclear Facilities, Notices of the Nuclear Safety and Security Commission, June 2021. No. 2021-10.
[11] NSSC, Regulation on the Methods of Verifying and Inspecting the Decommissioning Status of Nuclear Facilities, Nuclear Safety and Security Commission, June 2021. Notice of NSSC No. 2021-12.
[12] NSSC, Standards for the Re-use of Site and Remaining Buildings after the Decommissioning of Nuclear Facilities, Notices of the Nuclear Safety and Security Commission, June 2021. No. 2021-11.
[13] KINS, Safety Review Guideline on Final Decommissioning Plan for Decommissioning Approval, Korea Institute of Nuclear Safety, June 2020. KINS/GE-G002.
[14] KEI, Environmental Strategies for Site Reuse of Decommissioned Nuclear Power Plants, Korea Environment Institute, 2019. ISSN 2288-9043.
[15] KORAD, 2021 Implementation Plan for Low and Intermediate Level Radioactive Waste, Korea Radioactive Waste Agency, 2021.
[16] T. Oritz, et al., Radiological protection during the dismantling of nuclear facilities, in: 13th International Congress of the International Radiation Protection Association, May 2012.
[17] IAEA, Decommissioning of Facilities, International Atomic Energy Agency, 2014. GSR Part.6.
[18] G. Jeong, Quantitative assessment model of nuclear facility decommissioning process risks, in: Korean Radioactive Waste Society Conference, 2011.
[19] IAEA, Management of Nuclear Power Plant Projects, International Atomic Energy Agency, 2020. NG-T-1.6.