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Comparison of the DeSa Project and the Preliminary Decommissioning Plan for Shin-Kori Units 5 and 6 in Terms of Graded Approaches

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Abstract A graded approach applies safety requirements differentially, depending on the risk potential. An advantage of applying a graded approach is that safety assessments can be conducted repeatedly by focusing on areas with relatively higher risk than on those with low risk when decommissioning a nuclear power plant (NPP). The International Atomic Energy Agency (IAEA) recommends applying a graded approach to decommissioning NPPs worldwide. In Korea, the definition of the graded approach requires to be clarified. This study compared the decommissioning method used in Korean NPPs with the IAEA graded approach and examined whether the graded approach can be applied to decommissioning NPPs in Korea. As a result of the comparison, the preliminary decommissioning plan for Shin-Kori Units 5 and 6 showed that the decommissioning method for Korean NPPs is similar to the five-step IAEA graded approach.

Key words: Graded approach, Decommissioning, Nuclear power plant, Safety assessment

1. INTRODUCTION

Currently, Korea has 26 nuclear power plants (NPPs), including two permanently shutdown reactors waiting for decommissioning approval [1]. More NPPs will be decommissioned in the future because the design life of 12 NPPs will expire by 2030 [2,3]. Worldwide, graded approaches are applied to decommissioning NPPs. A graded approach enables subdivided processes while decommissioning an NPP to enable safety assessments to focus on high-risk work. However, Korea requires a clear definition of the graded approach. Current decommissioning plans for Korean NPPs are based on the ease of work and radiation risk during decommissioning. The International Atomic Energy Agency (IAEA) has suggested that if graded approaches are applied to safety assessment, they can save effort and time in decommissioning and aid a decommissioning licensee to focus on the most dangerous tasks. In 2004, the IAEA launched the DeSa project, the international project on the evaluation and demonstration of safety during decommissioning of facilities using radioactive material, to provide specific guidance on the safety assessment for the decommissioning of nuclear facilities using the graded approach. This study investigated the definition and requirements of the IAEA's graded approach, including cases of its application in the IAEA DeSa project. The applicability of graded approaches to decommissioning NPPs in Korea was also investigated by analyzing the preliminary decommissioning plan (PDP) for Shin-Kori Units 5 and 6.

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2. MATERIALS AND METHODS

2.1. Investigation of the IAEA graded approach

Currently, a differential approach is required worldwide to develop, review, and update decommissioning plans for facilities that use radioactive materials, considering the complexity and risk of dismantling. The IAEA defines the graded approach as the differential application of safety requirements to various types of facilities, such as NPPs, research reactors, and laboratories, depending on the risk potential [4]. The IAEA provides five steps for applying the graded approach to facilities [4]. In Step 1, a safety assessment of the decommissioning facilities is conducted according to the relevant regulations of each country. Step 2 requires the radiological characterization of the facility in advance. Step 3 presents a method for classifying the decommissioning areas of a facility using the radiological characteristics obtained from Step 2. According to IAEA guidelines, decommissioning areas are classified into five categories: uncontaminated, potentially contaminated, contaminated, high dose rate, and high dose rate areas without direct access [4]. This classification of decommissioned areas has the significant advantage of simplifying safety assessments and reducing efforts to determine the reliability of the assessment results. Step 4 presents the implementation of safety assessments for workers, the general public, and the environment using a graded approach during decommissioning. Step 5 involves identifying other considerations when implementing the results of the safety assessment conducted in the previous step. Table 1 lists the five steps of the graded approach proposed by the IAEA [4]. In addition, various considerations must be identified when applying the graded approach. The IAEA Safety Standards No. WS-G-5.2 presents considerations for implementing graded approaches, as listed in Table 2 [5].

2.2. Investigation of graded approach methods in preliminary decommissioning plans for Korean nuclear power plants

There are two permanently shutdown NPPs in Korea,

Table 1. Five steps of implementing a graded approach

Step	Task
1	Identification of requirements for the safety assessment by the regulatory framework
2	Preliminary analysis of the facility
3	Hazard categorization and preliminary hazard assessment of the facility and its systems, structures, and components
4	Safety assessment for decommissioning
5	Implementation of safety assessment results

Table 2. Considerations for implementing a graded approach

No.	Contents
1	Purpose of the safety assessment
2	Scope of the assessment
3	End state of the decommissioning facility
4	Radiological hazard potential (activity inventory, radiological characteristics, the chemical and physical state of the radioactive material)
5	Radiological criteria with which the safety assessment results will be compared
6	Size and type of the facility, including its complexity
7	Site characteristics
8	Presence and initiating events for incident and accident sequences
9	Likelihood and consequences of hazards
10	Physical state of the facility at the start of the decommissioning work
11	Complexity of decommissioning activities
12	Availability of applicable safety assessment for this or other similar facilities or proposed decommissioning activities

Table 3. Operating and permanently shutdown NPPs in Korea

NPPs		Type	Net capacity (MWe)	Commercial operation	Shutdown
Hanbit	1	PWR	950	25.08.1986	
	2	PWR	950	10.06.1987	
	3	PWR	1000	31.03.1995	
	4	PWR	1000	01.01.1996	
	5	PWR	1000	21.05.2002	
	6	PWR	1000	24.12.2022	
Kori	1	PWR	587	29.04.1978	18.06.2017
	2	PWR	650	25.07.1983	
	3	PWR	950	30.09.1985	
	4	PWR	950	29.04.1986	
Shin Kori	1	PWR	1000	28.02.2011	
	2	PWR	1000	20.07.2012	
Saeul	1	PWR	1400	20.12.2016	
	2	PWR	1400	29.08.2019	
Hanul	1	PWR	950	10.09.1988	
	2	PWR	950	30.09.1989	
	3	PWR	1000	11.08.1998	
	4	PWR	1000	31.12.1999	
	5	PWR	1000	29.07.2004	
	6	PWR	1000	22.04.2005	
Wolsong	1	PHWR	687	22.04.1983	24.12.2019
	2	PHWR	700	01.07.1997	
	3	PHWR	700	01.07.1998	
	4	PHWR	700	01.10.1999	
Shin Wolsong	1	PWR	1000	31.07.2012	
	2	PWR	1000	24.07.2015	

Kori Unit 1 and Wolsong Unit 1, but no NPP has been approved for final decommissioning [6]. The current status of operating and permanently shutdown NPPs in Korea are listed in Table 3 [7]. Investigating the graded approach for Korean NPPs during decommissioning is difficult because no NPPs have been approved for decommissioning in Korea. This study investigated the graded approach method in Korean NPPs using the PDP rather than the final decommissioning plan (FDP). The differences between the FDP and PDP are given in Table 4 [8]. The FDP presents the results of applying the PDP safety assessment method. In other words, the PDP provides a safety assessment method for an NPP to be decommissioned after the end of its design life. The FDP then delivers safety assessment results using a specific decommissioning plan based on the safety assessment method in the PDP. Furthermore, the PDP provides an approximate plan for radiation protection, fire protection, radioactive waste management, and environmental monitoring, whereas the FDP includes detailed implementation plans. Therefore, this study compared the decommissioning method of the PDP for Shin-Kori Units 5 and 6, which are the most recent Korean NPPs, with the graded approach method in the IAEA DeSa project, focusing on the five steps of the graded approach provided by the IAEA.

3. RESULTS AND DISCUSSION

3.1. Graded approach in the IAEA DeSa project

The IAEA DeSa project used the international experience to assess the safety of decommissioning activities and to develop approaches. The DeSa project provided an opportunity to exchange information and experiences related to the safety assessment of decommissioning through meetings. The DeSa project also developed a methodology for safety assessments and demonstrations during decommissioning. This methodology can be used to determine whether the safety assessment of the graded approach can be applied. The safety assessment methodology using the graded approach applied to NPP decommissioning in the DeSa project is shown in Fig. 1 [6,9]. The DeSa project represents an example of the application of a graded approach to power generation reactors, research reactors, and nuclear laboratories. Because power generation reactors are major targets for decommissioning in Korea, this study examined the experience of the DeSa project for power generation reactors.

The DeSa project implemented the five-step graded approach proposed by the IAEA for safety assessments. In the DeSa project, a safety assessment was performed using a graded approach for shutdown reactors and containment spray cooling systems. A graded approach was also applied to the radiological characterization of facilities and data acquisition. The graded approach applied to the safety assessment uses hazard and operability analysis (HAZOP) to screen for and group risk factors during decommissioning. HAZOP is a technique in which risk and operability analy-

Table 4. Comparison of the preliminary decommissioning plan with the final decommissioning plan

Category	Preliminary decommissioning plan	Final decommissioning plan
1. Overview of the decommissioning plan	• Background, purpose, overview of the facility site	Same as left
2. Project management	• Organization and personnel performing decommissioning work • Decommissioning cost and rationale • How to secure financial resources	Same as left
3. Site and environmental impact	• Site status of facilities subject to decommissioning • Environmental status of the site and surrounding areas, such as weather, geology, hydrology, and marine characteristics • Evaluation results of radioactive materials and radiation sources in facilities and sites	Same as left
4. Decommissioning strategies and methods	• Immediate or delayed decommissioning	• Decommissioning strategy, method, schedule
5. Design characteristics and measures for ease of decommissioning	• Design characteristics of ALARA principles applied during the dismantling • Records of decommissioning impact events during operation	• Validity of design characteristics to secure the ease of decommissioning
6. Safety evaluation	• Assessment methodologies, including dose and risk	• Evaluation results
7. Radiation protection	• ALARA implementation methodology	• Proof of ALARA implementation • Radiation protection plan
8. Decontamination activities	• Decontamination technology and application method	• Decontamination equipment • Decontamination factor
9. Waste management	• Waste management plan in operation • Disposal method of waste during decommissioning	• Waste type, quantity, concentration • Monitoring, storage, treatment, and disposal of waste materials
10. Environmental impact assessment	• Environmental monitoring plan during operation and decommissioning • Environmental impact assessment method	• Environmental impact assessment results
11. Fire protection	• Schematic fire protection plan	• Specific fire protection plan based on a notice from Nuclear Safety and Security Commission

ses are performed by experienced experts in various fields, including NPP operators, engineers, radiation protection experts, safety engineers, and human factor experts. The DeSa project screened for risk and initial events using HAZOP and identified appropriate scenarios for detailed analysis. The DeSa project used a checklist to screen initial events. In addition, the DeSa project screened the initial events and risks associated with the incident to identify scenarios that required further analysis, detailed potential risks, and applied a graded approach based on importance (high-risk order). The graded approach applied in radiological characterization and data acquisition determines the list of radionuclides through historical literature review, sampling, and characterization, and uses the list to rate the level of risk

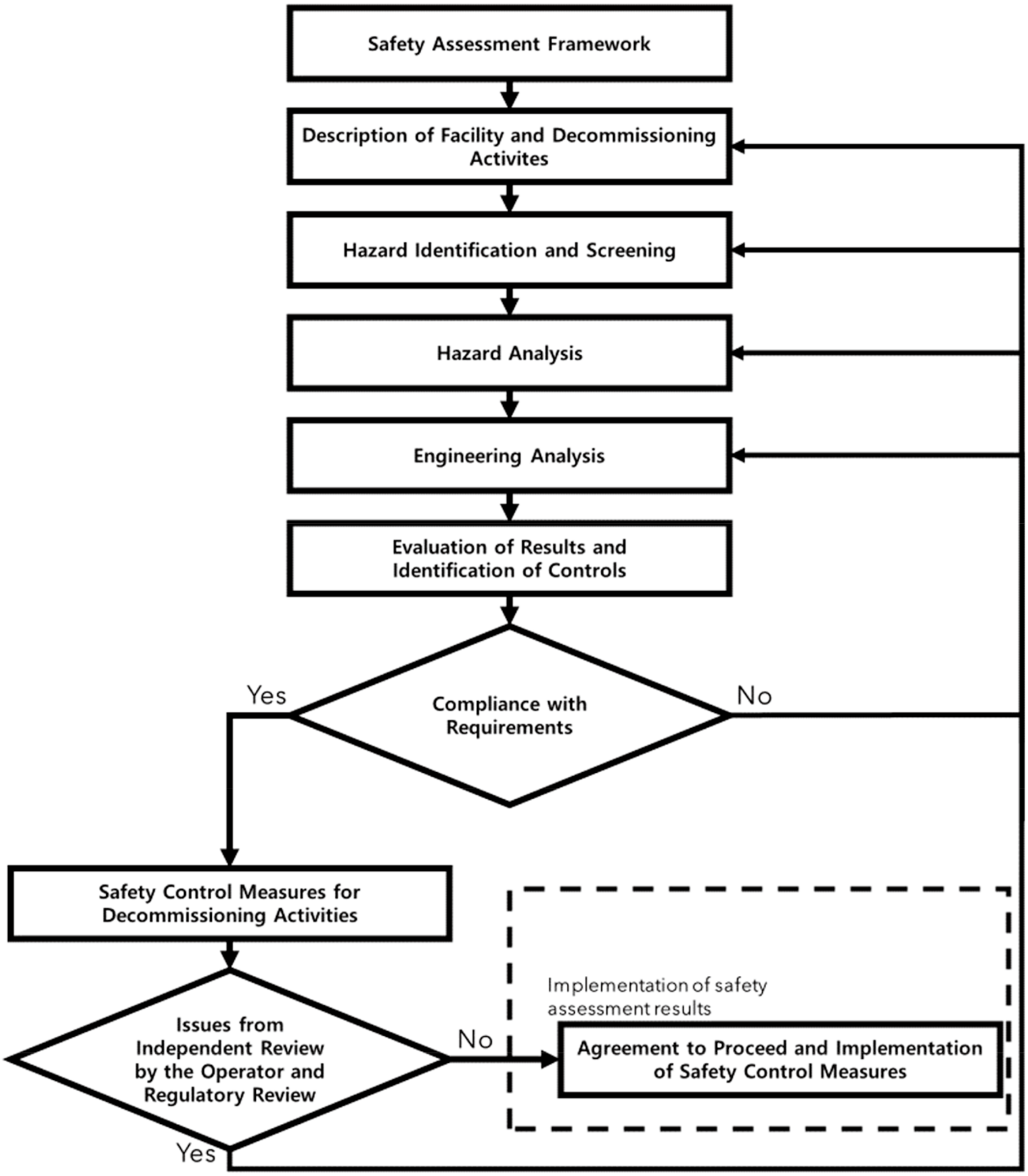

Fig. 1. Methodology of safety assessment applied to decommissioning the NPP in the DeSa project.

during decommissioning. This graded approach keeps the safety evaluation as simple as possible to minimize the safety evaluation effort during decommissioning. The results of these assessments ensure that the risk assessment is fully performed and optimized to be reasonably achievable. Furthermore, the previous evaluation results enable a graded analysis of risks and safety evaluations, focusing on high-risk areas. Through this process, mitigation measures to reduce risk can be implemented. Therefore, the graded approach can be applied to selectively perform safety evaluations according to the level of risk in a specific system.

3.2. Comparison of IAEA graded approach and decommissioning methods of preliminary decommissioning plans for Korean nuclear power plants

In this study, the decommissioning method of the PDPs for Shin-Kori Units 5 and 6, the latest NPPs in Korea, was compared with the five-step IAEA graded approach. In Step 1, the DeSa project used dose limits for radiation workers and the general public, which are presented in IAEA Safety Standards Series No. WS-G-5.2 [5]. In Korea, the current dose limits of the Enforcement Decree of the Nuclear Safety Act are applied to the safety assessment when decommissioning NPPs [10,11]. The dose limits in Korea are the same as those presented in the IAEA Safety Standards Series No. WS-G-5.2 [5,11].

In Step 2, the DeSa project utilized facility and field data, facility history, and previous safety assessment results, and selected hazards to radiation workers and the general public in advance in normal and accident scenarios. In particular, the DeSa project identified the number of people in each team for each decommissioning activity and created lists of preparatory and finishing tasks for decommissioning. In Korea, there is no history of decommissioning commercial reactor facilities. Thus, this study investigated the application of Step 2 of the graded approach to Korean NPPs by referring to the preliminary safety analysis report (PSAR) for Shin-Kori Units 5 and 6 [12]. According to the PDP for Shin-Kori Units 5 and 6, decommissioning activities are initiated by the selection of decontamination technology [11]. The PDP for Shin-Kori Units 5 and 6 provides general information on the decommissioning technology, cutting method, and selection of cutting equipment; however, the list of decommissioning works is not included. To select hazards for radiation workers and the general public in normal and accident scenarios, the DeSa project identified major scenarios using the HAZOP method and used these scenarios for detailed analysis. In contrast, the PDP for Shin-Kori Units 5 and 6 used IAEA Safety Reports Series No. 77 to select hazards for radiation workers and the general public during normal and accident scenarios and requires the analysis of decommissioning scenarios with selected hazards [9,11].

In Step 3, the IAEA graded approach requires a list of radionuclides determined by sampling and measurement for radiological characterization and classification. The distribution of radioactivity within a facility must also be identified to classify the decommissioning areas and systems contaminated by radioactive materials. The DeSa project estimated a list of radionuclides based on radioactivity measurement results during the NPP operation and after the permanent shutdown. In addition, the DeSa project conducted measurements and sampling to quantify the level of radioactive contamination after the permanent shutdown of the NPP and identified the system and decommissioning areas contaminated with radioactive materials. In particular, the DeSa project created a database containing radiation dose rates and the masses of contaminated system components. This database enables recording and management of the weight and radioactivity of contaminated materials. In contrast, the PDP for Shin-Kori Units 5 and 6 estimated the list of radionuclides by referring to the design criteria and expected radiation source term in the PSAR [11,12].

In Step 4, the IAEA graded approach requires a safety assessment to be performed using the data obtained in the previous steps. The DeSa project calculated the doses to radiation workers and the general public under normal and accidental decommissioning conditions using the screening results in Step 2 and the list of radionuclides obtained in Step 3. The PDP for Shin-Kori Units 5 and 6 quantified the radiological impacts on radiation workers and residents after identifying scenarios for normal decommissioning activities, abnormal incidents, and accidents [11].

Finally, Step 5 of the IAEA graded approach requires identifying whether there are other considerations when implementing the results of the safety assessment. These considerations are used by the company or organization performing the decommissioning to evaluate the strategy or apply a graded approach to safe and economic decommissioning. The DeSa project developed necessary measures by comparing the performance data of the safety assessment with dose limits. In contrast, the PDP for Shin-Kori Units 5 and 6 requires radiation workers and residents to receive radiation exposure below the dose limits set by the Enforcement Decree of the Nuclear Safety Act, which is the same as the dose limit mentioned in the DeSa project. The performance data of the safety assessment presented in the PDP for Shin-Kori Units 5 and 6 were used to develop measures to reduce radiation exposure to within an acceptable level, protect radiation workers and residents, and mitigate radiological impact [11]. A comparison of the IAEA graded approach and decommissioning methods of the PDP for Korean NPPs is presented in Table 5.

Overall, the PDP for Shin-Kori Units 5 and 6 showed that the decommissioning method for Korean NPPs is similar to the five-step IAEA graded approach. The DeSa project focused on high-risk work and provided mitigation measures to reduce this risk. For Korean NPPs, because standards have already been determined for each step, risks

Table 5. Step-by-step comparison between the DeSa project and the preliminary decommissioning plan in Korean NPPs

Step	DeSa project	Shin-Kori Units 5 and 6 (Korean NPPs)
1	IAEA Safety Standards Series No. WS-G-5.2	Enforcement Decree of the Nuclear Safety Act No. 33193
2	• Describe the approach • Lists of preparatory and finishing works for decommissioning	• Describe the approach • Decommissioning work sequence
	Identify key scenarios with the HAZOP method and analyze them in detail	Analysis of hazards classified in IAEA Safety Reports Series No. 77
3	Estimate a list of radionuclides based on radioactivity measurement results during NPP operation and after permanent shutdown	Estimate the radionuclide inventory by referring to the design criteria and the expected radiation source term in the PSAR
	Measurement and sampling to quantify the level of radioactive contamination after the permanent shutdown of the NPP	Measurements and sampling to quantify the level of radioactive contamination after the permanent shutdown of the NPP
4	Calculate doses to radiation workers and the general public under normal and accidental decommissioning conditions using the screening results in Step 2 and the list of radionuclides obtained in Step 3	Quantify the radiological impact on radiation workers and residents after identifying the scenarios for normal decommissioning activities and abnormal incidents and accidents
5	Provide necessary actions by comparing baseline dose and safety evaluation data	Provide necessary measures by comparing the design target value below the baseline dose with the safety evaluation data

are calculated according to each standard, and measures are taken according to a predetermined method. Although the safety assessment method for Korean NPPs to be decommissioned is fully established in the PDP, it can be further improved if the safety assessment method focuses on areas with relatively higher risk than on areas with low risk when decommissioning NPPs.

4. CONCLUSION

This study compared the decommissioning method of PDPs for Shin-Kori Units 5 and 6, the latest NPPs in Korea, using the five-step IAEA graded approach. As a result of the comparison, Korean NPPs and DeSa projects satisfied the requirements of the graded approach; however, there were some differences in the decommissioning methods between Korean NPPs and DeSa projects. The DeSa project evaluated the risk of each task by listing the tasks in detail. This enables focusing on and taking mitigation measures in areas with relatively higher risk than in areas with low risk. In Korean NPPs, the risk is evaluated according to the procedures and scenarios of the decommissioning work, and mitigation will be taken on the selected scenario. Therefore, if Korean NPPs are decommissioned to evaluate the risk of each task by listing the tasks in detail, the safety assessment method for decommissioning NPPs will be improved.

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