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Preparation of Radiological Environmental Impact Assessment for the Decommissioning of Nuclear Power Plant in Korea

국내 원전 해체시 방사선환경영향평가 방안

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Kori unit 1, the oldest commercial nuclear power plant in South Korea, was permanently shut down in June 2017. There are a lot of things to consider in decommissioning nuclear power plants, and one of them is the radiological environmental impact assessment. Performed to promote the health and safety of residents around the nuclear power plant, radiological environmental impact assessment aims to confirm that off-site radiological dose from radioactive material released from the facility does not exceed the regulatory criteria. There are three main parts of environmental impact assessment: pre-decommissioning environmental monitoring, environmental monitoring during decommissioning, and impact on nearby residents. At present, although the Korea Nuclear Safety Act stipulates that radiological environmental impact assessment resulting from decommissioning should be carried out, the details have not been specified. Therefore, this paper compares and analyzes guidelines for evaluation of radiological environmental impacts of nuclear power plants overseas, and presents a draft on the assessment of radiological dose resulting from decommissioning according to the Korean situation.

Keywords: Radiological environmental impact assessment, Decommissioning plan, Environmental report

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국내 최초의 상업원전인 고리1호기가 2017년 6월에 영구 정지되었다. 고리1호기 해체를 시작으로 한국은 원전 해체시장에 본격적으로 발을 내딛는다. 원자력발전소 해체를 위해서는 고려해야 할 사항들이 많으며, 방사선환경영향평가 또한 그 중 하나이다. 방사선환경영향평가의 목적은 주변주민의 건강과 안전을 도모하기 위해, 해체 전 및 해체 중에 해당 시설에서 방출되는 방사성물질로부터 주변주민이 받는 피폭방사선량이 규제 제한치를 초과하지 않음을 확인하는 것이다. 현재 국내에는 해체시 방사선환경영향평가서를 작성하는데 필요한 세부지침이 미비한 상황으로, 다수의 원전 해체 경험을 보유한 미국의 해체시 방사선환경영향평가서를 비교・분석하여 국내 상황에 맞는 해체시 방사선환경영향평가 방안을 개발하였다.

중심단어: 방사선환경영향, 해체계획서, 환경영향평가서, 원전해체

1. Introduction

Kori Unit 1, Korea's first Nuclear Power Plant (NPP), was permanently shut down in June 2017. This is the first commercial NPP to be shut down after 30 years of operation and 10 years of extended operation. In addition, for other NPPs whose design life will be expired, if there is no extended operation, there will be an additional 12 more NPPs to be decommissioned by 2030. Major nuclear power nations such as the U.S., United Kingdom, and Germany have various nuclear decommissioning experience and have built a technology base. At the same time, they are continuously upgrading the technology to strengthen the safety, efficiency, and environmental friendliness of the technology.

Starting with Kori Unit 1, Korea will become a country that will start decommissioning in earnest. In order to decommission the NPP, it is necessary to prepare a draft of Decommissioning Plan (DP). The DP includes safety assessment, environmental impact assessment, radiation protection, fire protection, decontamination activities, and radioactive waste management. The environmental impact assessment, which will evaluate the impact of decommissioning on the environment and the exposures of nearby residents, will be a very important part to carry out decommissioning safely. However, in Korea, there are decommissioning experiences for small-scale low-radiation facilities through research reactor unit 1 and 2, but the experience for decommissioning large-scale radioactive facilities such as NPPs is still insufficient.

Radiological environmental impact assessment aims to confirm that off-site radiological dose from the radioactive material released from the facility does not exceed the regulatory criteria in order to promote the health and safety of residents around the nuclear power plant. The Nuclear Safety and Security Commission (NSSC) Notice No. 2015-8 requires the evaluation and description of environmental impact assessment in decommissioning. However, it is a guideline that an environmental impact assessment should be carried out.

Therefore, the purpose of this study is to review the overseas NPP decommissioning experience focusing on the radiological environmental impact assessment and to draw up a draft of radiological environmental impact assessment that reflects domestic situation.

2. Literature Review: IAEA and U.S.

In the United States (U.S.), the GEIS (General Environmental Impact Statement on Decommissioning of Nuclear Facilities, NUREG-0586) provides the guideline on environmental impact assessment in decommissioning nuclear power plants. The GEIS describes an analysis of environmental impacts from decommissioning activities that can be treated generically so that decommissioning activities for commercial nuclear power reactors conducted at specific sites will be bounded, to the extent practicable, by this

and appropriate previously issued environmental impact statements. In this study, we examined the documents related to the environmental impact assessment in decommissioning of nuclear power plants in the IAEA and the U.S., and reviewed the assessment items.

2.1 IAEA

The International Atomic Energy Agency (IAEA) provides a measure of safety standards for member states the safety of all countries using nuclear energy. The WS-R-5 "Decommissioning of Facilities Using Radioactive Material" published by the IAEA [1], establishes safety requirements related to the decommissioning of nuclear facilities. This document contains decommissioning procedures, plans and other requirements. The IAEA defines operators which establish decommissioning strategies must make a plan for decommissioning in accordance with waste management. The Decommissioning Plan (DP) should be established during the design, operation, and shut down phases, and the operator must update the DP periodically at least every five years, especially during the operational phase. The IAEA Safety Reports Series No.45,"Standard Format and Safety Related Decommissioning Documents" defines guidelines for the creation of a minimum DP to ensure protection of the public, workers and environment. Most countries who have nuclear power plant are based on these guidelines when establishing guidelines for their DP. Table 1 shows the contents for the IAEA DP. The environmental assessment are listed in contents 10.

Table 1. The Contents of the Decommissioning Plan [2]

1. Introduction
2. Facility Description
3. Decommissioning Strategy
4. Project Management
5. Decommissioning Activities
6. Surveillance and Maintenance
7. Schedule for surveillance and maintenance
8. Waste containing both radionuclides and other hazardous material
9. Safety Assessment
10. Environmental Assessment
    - 10.1 Background data
    - 10.2 Description of Project
    - 10.3 Environmental protection program
    - 10.4 Effluent monitoring program
    - 10.5 Effluent control program
11. Health and Safety
12. Quality Assurance
13. Emergency Planning
14. Physical Security and Safeguards
15. Final Radiation Survey

2.2 United States (U.S.)

The U.S. has the largest number of nuclear decommissioning experiences in the world. Until now, the U.S. has decommissioned 15 nuclear power plants and has various decommissioning cases. The U.S. NPPs decommissioning

Table 2. Contents of Decommissioning Phase of the U.S. NPPs

Phase	Items	Contents
Pre-Decommissioning	· Permanent Shut down Notice	· Submission a permanent shut down certification to NRC within 30 days after notifying permanent shut down
	· PSDAR[1] Submission	· Submit PSDAR to NRC within 2 years from the date of the permanent shut down decision
During Decommissioning	· LTP[2] Submission	· Submit LTP to NRC before license end date
After Decommissioning	· FSSR[3] Submission	· Submit FSSR to NRC after decommissioning

1) PSDAR (Post-Shutdown Decommissioning Activities Report)
2) LTP (License Termination Plan)
3) FSSR (Final Status Survey Report)

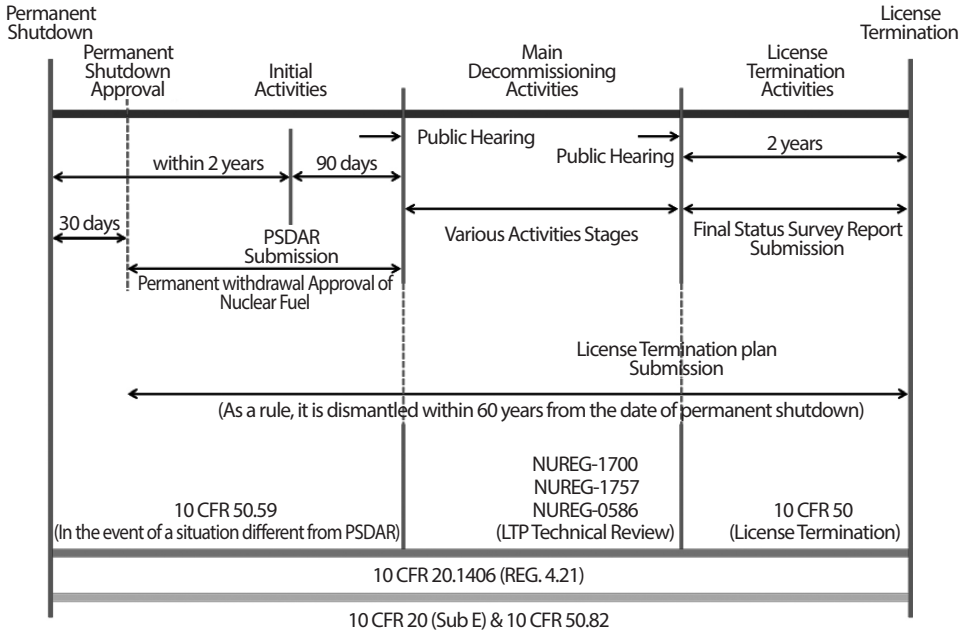

Fig. 1. Regulatory Process for the U.S. NPPs Decommissioning.

Table 3. The Contents in GEIS required by the U.S. NRC

1. Onsite/Offsite Land Use	7. Threatened and Endangered Species	13. Environmental Justice
2. Water Use	8. Radiological	14. Culture, Historic, and Archeological Resources
3. Water Quality	9. Radiological Accidents	15. Aesthetic Issues
4. Air Quality	10. Occupational Issues	16. Noise
5. Aquatic Ecology	11. Cost	17. Transportation
6. Terrestrial Ecology	12. Socioeconomics	18. Irreversible and Irretrievable Commitment of Resources

process is as follows. The regulations of the United States are related to the Atomic Energy Act and the Environmental Protection Act, Federal Regulations 10CFR, Nuclear Regulatory Commission (NRC) Regulatory Guides and NRC's reports (NUREG etc.). Decommissioning related regulatory procedures, submission documents, and end-of-license criteria are specified in the U.S. federal regulations. The document review and environmental survey guideline follow in accordance with the NRC regulatory guide. In 1997, the U.S. enforced its regulatory system and License Termination Rule (LTR) procedures for decommissioning. The relevant regulations are specified in Subpart E of Federal Regulations 10CFR20 and in Federal Regulations 10CFR50.82. The U.S. regulatory process related to nuclear decommissioning is shown in Table 2 and process of decommissioning phase is shown in Fig. 1.

2.2.1 GEIS (General Environmental Impact Statement on Decommissioning of Nuclear Facilities, NUREG-0586)

The U.S. National Environmental Policy Act (NEPA) requires the NRC to assess the potential impact on the environment before issuing permits or operation permit. Ac-

cordingly, the NRC requires the applicant to submit an Environmental Report to license the facility. Procedures and requirements for environmental impact assessment are set out in 10CFR Part 51 (Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions). Also, the U.S. conducts an assessment of radiological environmental impacts based on the description in the General Environmental Impact Statement (GEIS) when decommissioning. The GEIS is to provide the results of environmental assessment that can be treated generically so that decommissioning activities for commercial nuclear power reactors conducted at specific sites will be bounded, to the extent practicable, by this and appropriate previously issued environmental impact statements [3].

The U.S. decommissioning documents based on GEIS are PSDAR and LTP. These documents contain information on radiological environmental impact assessment of nuclear decommissioning. The evaluation items of GEIS are shown in Table 3.

Notably, in the U.S., permission also to operate a nuclear facility is maintained at the decommissioning stage. And there is no PSDAR review and approval procedure for decommissioning (The NRC does not approve the PSDAR). The U.S. has experienced the decommissioning of many nuclear power plants. Based on this, they have only a procedure for receiving PSDAR similar to the decommissioning plan and explaining it to the residents. Instead, at the end of the license, which is the completion phase of the decommissioning process, they have a system that reviews and approves the LTP and Final Status Survey Report (FSSR) to terminate the license upon completion of decommissioning.

2.2.2 PSDAR (Post-Shutdown Decommissioning Activities Report)

The licensee must submit a permanent shut down certification to the NRC within 30 days since announcing that reactor will be permanently shut down. They also must submit the PSDAR to the NRC within 2 years from the date of the permanent shut down decision. The PSDAR is not required to be approved by the NRC, but it may require supplementation if the content of the PSDAR violates the law. The NRC shall notify the PSDAR to Federal Register and hold a public hearing. Before preparing the PSDAR, the licensee should assess the site-specific potential environmental impact of decommissioning activities. Potential environmental impacts from decommissioning activities should be compared to similar impacts from the Final Environmental Statement (FES), GEIS for decommissioning, and the site-specific environmental impact assessment. The PSDAR must include:

- A description and schedule for the planned decommissioning activities
- An estimate of the expected costs
- A discussion that provides the means for concluding that the environmental impacts associated with the decommissioning activities will be bounded by appropriately issued environmental impact statements (EISs)

The licensee cannot perform any major decommissioning activities until 90 days after the NRC has received the PSDAR. The PSDAR is not required to be approved by the NRC, but it may be required the regulator as a supplement if there is something that violates the laws and regulations of the PSDAR.

2.2.3 LTP (License Termination Plan) [4]

The licensee shall submit the License Termination Plan (LTP) to the NRC for approval by the NRC prior to at 2 years the planned license termination date in the PSDAR. Finally, the licensee submits the FSSR to the NRC after the decommissioning is completed. The LTP contains supplemental environmental reports that describe new or important environmental changes related to the termination activity proposed by the license. The NRC concludes its confirmatory surveys after review and approval, and terminates the license. The LTP must include:

Table 4. Comparison of Environmental Impact Assessment Items in the PSDAR

	Kewaunee	Rancho Seco	Crystal River Unit 3
1.Onsite/Offsite Water Use	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
2.Water Use	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
3.Water Quality	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
4.Air Quality	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
5.Aquatic Ecology	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
6.Terrestrial Ecology	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
7.Threatened and Endangered Species	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
8.Radiological	Total Occupational Radiation Exposure : 737 person-rem	Total Occupational Radiation Exposure : 460 person-rem	Total Occupational Radiation Exposure : 308-664 person-rem
9.Radiological Accidents	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
10.Occupational Issues	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
11.Cost	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
12.Socioeconomics	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
13.Environmental Justice	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
14.Cultural, Historic, and Archeological Resources	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
15.Aesthetic Issues	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
16.Noise	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS
17.Transportation	Class A : 133,498 ft^3 Class B : 2,207 ft^3 Class C : 341 ft^3 GTCC : 58 ft^3	Bounded by GEIS	Class A : 136,858 ft^3 Class B : 876 ft^3 Class C : 462 ft^3 GTCC : 1,785 ft^3
18.Irreversible and Irretrievable Commitment of Resources	Bounded by GEIS	Bounded by GEIS	Bounded by GEIS

- A site characterization
- Identification of remaining dismantlement activities
- Plans for site remediation
- Detailed plans for the final radiation survey
- A description of the end use of the site, if restricted
- An updated site-specific estimate of remaining decommissioning costs
- A supplement to the environmental report describing any new information or significant environmental change associated with the licensee's proposed termination activities

The NRC releases the LTP to the public and holds a public hearing. And the NRC authorizes LTP if it proves

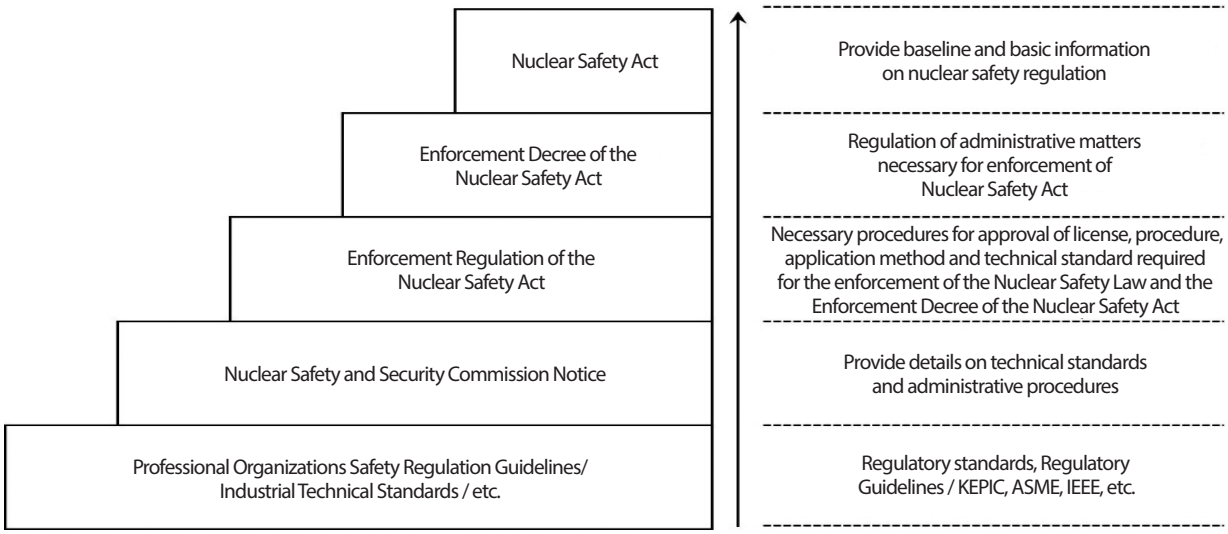

Fig. 2. Domestic Nuclear Regulation System.

that it is not harmful to the health and safety of the general public. When the licensee conducts as planned and the NRC confirmed the following, the license is terminated.

- The remaining dismantlement has been performed in accordance with the approved LTP
- The final radiation survey and associated documentation demonstrate that the facility and site are suitable for release in accordance with the LTR (License Termination Rule).

2.2.4 Comparison of Environmental Impact Assessment among the U.S. NPPs

Table 4 shows the comparison of environmental impact assessment items in the PSDAR [5, 6, 7]. In particular, Kewaunee is the same type of reactor as Kori Unit 1, so it can be a reference.

In the U.S., the environmental impact assessment is compared with the GEIS when decommissioning a nuclear power plant, and decides whether an environmental impact assessment that requires site characteristics should be made. As a result of the review of the U.S. nuclear decommissioning environmental impact assessment, there was no environmental impact assessment, and all nuclear power plants were bounded by GEIS.

3. Literature Review: Korea

Considering overseas cases through the literature review and domestic situation, it is necessary to review the preparation of Radiological Environmental Report (RER) in NPP decommissioning. First of all, it need to review the guidelines and assessment items for radiological environmental impact assessment through domestic laws and regulations, and to confirm at which stage is carried out the environmental impact assessment in NPP decommissioning.

3.1 Domestic Regulation

The framework for domestic nuclear safety regulations is shown in Fig. 2. The Nuclear Safety Act is the highest law and this is a law that stipulates matters concerning the prevention of disasters caused by nuclear research, development, production, use and radiation, and public safety. Next, there is the Enforcement Decree of the Nuclear Safety Act

Table 5. Domestic Nuclear Act on Radiological Environmental Impact Assessment

Nuclear Safety Act	Enforcement Decree of the Nuclear Safety Act
Article 10 (Construction Permit). ② In compliance with article ①, a person who wishes to obtain permission shall submit to the commission a copy of the license application with radiological environmental impact assessment report, a preliminary safety analysis report, a quality assurance plan for construction, a decommissioning plan for power generation reactors and related facilities and other documents prescribed by the Prime Minister.	Article 143 (Radiological Environmental Impact Assessment Report or the Drafting of the Decommissioning Plan Submission, etc.). ① If the operator intends to collect opinions of resident in accordance with Article 103(1), (2) and (4), the radiological environmental impact assessment report according to Article 103(3) of the Act or decommission plan shall be submitted to the head of the organization.
Article 20 (Operation Permit). ② In compliance with article ①, a person who wishes to obtain permission shall submit to the commission a license application a copy of the license for the operation of the reactor and related facilities, the final safety analysis report, accident management plan (including major accident management plan), the quality assurance plan for operation, evaluation plans, decommissioning plans for power generating reactors and related facilities, emission plans for liquid and gaseous radioactive materials, and documents prescribed by the Prime Minister.	Regulations on Technical Standards such as Reactor Facilities [8]
	Article85-16 (Decommissioning Environmental Impact Assessment). ① The operator shall evaluate the expected radiological environmental impact assessment due to the decommissioning of the reactor facility. ② The operator shall establish and implement an environmental monitoring plan before and during decommissioning of the reactor facilities.

that specifies requirements for the management and operation. And then The Enforcement Regulations of the Nuclear Safety Act prescribe the matters delegated by the Enforcement Decree of the Nuclear Safety Act and the Nuclear Safety Act and the matters necessary for its enforcement.

The Nuclear Safety Act and Enforcement Decree of the Nuclear Safety Act related to radiological environmental impact assessment is shown in Table 5.

According to the current Nuclear Safety Act, the applicant for the construction and operation permission of the nuclear reactor for power generation should carry out the radiological environmental impact assessment. In accordance with the provisions of the Nuclear Safety and Security Commission (NSSC) Notice No. 2015-8 "Regulation for the Preparation of Nuclear Decommissioning Plans" [9], it is stipulated that a decommissioning safety assessment and radiological environmental impact assessment should take place together with the plan.

3.2 Radiological Environmental Impact Assessment

The contents of the preparation of radiological environmental impact assessment report are specified in the NSSC Notice No. 2016-4 Article 5 "Regulations for the Preparation of Radiological Environmental Impact Assessment Report for Nuclear Facilities at the Nuclear Energy Safety Commission" (Table 6). Applicants for nuclear power construction permit must submit a RER to the NSSC after conducting radiological environmental impact assessment under the Nuclear Safety Act. When preparing the RER, draft of a RER should be prepared, and public hearings should be held to collect opinions of residents and considers them in the contents of the RER (Nuclear Safety Act Article 103-1). The NSSC Notice No. 2016-16 specifies the requirements to be satisfied by the radiological impacts of radioactive effluents discharged to the environment due to the operation of nuclear power plants.

The assessment items of RER can be classified into normal and accident. Radiological dose at Exclusion Area Boundary (EAB) by radioactive effluents released into the environment during normal operation of the reactor facility shall be maintained below the levels specified in Table 7 (NSSC Notice No. 2016-16 "Standards on Radiation Protection") [10]. Also, the dose of radioactive material released to the environment in the event of a nuclear reactor accident shall not exceed the value specified in the NSSC Notice No. 2014-10 "Technical Standards for Location of Reactor Facilities".

Table 6. Radiological Environmental Impact Assessment Items for Operation Permit

Items	Contents
1. Overview of construction plan	1.1 Necessity of construction 1.2 Basis for environmental impact assessment 1.3 Progress of business 1.4 Construction plan 1.5 Reason for site selection
2. Environmental status	2.1 Site status 2.2 Land use 2.3 Marine use 2.4 Weather and atmospheric diffusion 2.5 Water and watershed diffusion 2.6 Oceanic and marine diffusion 2.7 Population 2.8 Environmental radiation /performance status
3. Nuclear Power plant status	3.1 Appearance 3.2 Reactors and steam·electric systems 3.3 Fuel storage facility 3.4 Radioactive waste treatment system 3.5 Radiation source
4. Impact from construction	4.1 Dose calculation model 4.2 Assumptions for does calculation 4.3 Dose calculation 4.4 Summary of annual exposure dose
5. Impact from operations	5.1 Exposure pathway 5.2 Exposure dose evaluation
6. Impact from accidents	6.1 Accident assumptions 6.2 Radiation source 6.3 Evaluation method 6.4 Exposure dose evaluation 6.5 Resident protection measures
7. Environmental monitoring plan	7.1 Environmental monitoring before operation 7.2 Environmental monitoring during operation
8. Overall assessment	8.1 Overview 8.2 Assessment by case 8.3 Assessment results

3.3 Nuclear Power Plant Decommissioning Procedure

There are three major strategies to decommission a nuclear power plant: DECON, SAFSTOR, and ENTOMB [3]. DECON is defined as the immediate dismantling soon after the nuclear facility closes with equipment, structures, and parts of the facility containing radioactive contaminants being removed or decommissioned. SAFSTOR is known as “deferred dismantling” where the facility is maintained and monitored, which allows for radioactive decay prior to the plant being dismantled and the property decontaminated. ENTOMB is defined as the permanent encasement of radioactive contaminants on the site in structurally sound materials such as concrete. The facility is maintained and monitored until the radioactivity levels reach to a set point.

Kori Unit 1 will be decommissioned by DECON. The DECON type can reduce decommissioning costs compared to SAFSTOR and can be reused the site quickly. It also

has a great advantage in that it can quickly acquire decommissioning techniques. The Kori Unit 1 decommissioning roadmap is shown in Fig. 3.

The decommissioning procedure is divided into 4 stages:

- Preparation and approval of the decommissioning plan
- Spent fuel cooling and carrying out
- Main dismantling
- Site restoration

The Final Decommissioning Plan (FDP) must be submitted to the NSSC for approval of decommissioning within 5 years after the permanent shut down of the NPP. In the first half of 2019, Korea Hydro & Nuclear Power (KHNP), the licensee, plans to prepare a decommissioning plan that includes decommissioning plans, methods, safety assessment, environmental impact assessment, radioactive waste management, and collects opinions from residents and after that they must submit to the NSSC. The NSSC will evaluate the appropriateness of the decommissioning plan through the IAEA's peer review until June 2022 and decide whether to approve it. The environmental impact assessment of the FDP describes the environmental impacts caused by decommissioning of nuclear power plants in a quantitative manner. In order to confirm the extent of this, it shall establish and describe an environmental monitoring plan before and during decommissioning of nuclear facilities.

Table 7. Standards for Liquid and Gaseous Emissions due to NPP Operation

1. Criteria to be applied to the design of the facility
   A) Annual dose at the exclusion area boundary by gaseous emissions
      1) Absorbed dose of air by gamma rays : 0.1 mGy
      2) Absorbed dose of air by the beta ray : 0.2 mGy
      3) Effective dose due to external exposure : 0.05 mSv
      4) Skin equivalent dose due to external exposure : 0.15 mSv
      5) Organ dose equivalent due to particulate, ^{3}H, ^{14}C, Iodine and long-term equivalent dose of human body by radioiodine : 0.15 mSv
   B) Annual dose at the exclusion area boundary by liquid emissions
      1) Effective dose : 0.03 mSv
      2) Organ equivalent dose : 0.1 mSv
2. Criteria to be applied when operation multiple nuclear facilities in the same site
   A) Annual dose at the exclusion area boundary
      1) Effective does : 0.25 mSv
      2) Thyroid equivalent dose : 0.75 mSv

4. Review Results

4.1 Review of the Need to Prepare Separate Radiological Environmental Impact Assessment in Decommissioning

In the overseas case (United States, Canada, United Kingdom, and France), the environmental impact assessment and the radiological environmental impact assessment are operating in an integrated. In other words, the environmental impact assessment includes a radiological environmental impact assessment. In Table 8, the decommissioning plan of the IAEA is compared with the domestic decommissioning plan.

Environmental impact assessment is included in Chapter 10 of the IAEA's Decommissioning Plan (DP). The environmental assessment of the IAEA is normally a separate document that is referenced and summarized in the DP. The conclusions of the assessment are provided in the DP. Since the environmental assessment is normally a separate document, some information is repeated, which would not be required if it is directly incorporated in the DP [2]. The domestic DP also includes the Environmental Impact Assessment in Chapter 10. The comparison of the IAEA and domestic DP shows that both documents are very similar.

In this study, it is considered appropriate to compose the environmental impact assessment in the DP without applying separate radiological environmental impact assessment.

4.2 Consideration for Decommissioning Radiological Environmental Impact Assessment

The environmental impact assessment for decommissioning Kori unit 1 should be followed by the NSSC Notice

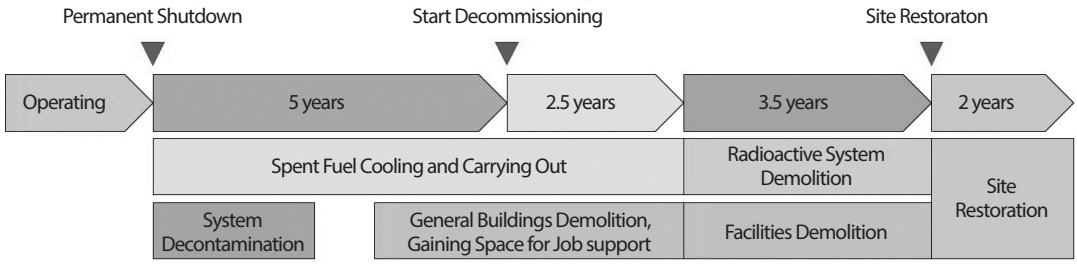

Fig. 3. Process for Kori Unit-1 Decommissioning.

Table 8. Comparison of the IAEA Technical Report and Domestic Decommissioning Plan Item

IAEA Technical Report (Safety Report Series No. 45)	Korea (Nuclear Safety and Security Commission Notice No.2015-8)	Sub-contents suggested
1. Introduction	1. Overview of decommissioning plan	i. Overview ii. Types and characteristics of facilities to decommissioning target iii. Accident and radiation leak history
2. Facility description		
3. Decommissioning Strategy	2. Business Management organization	i. Organization ii. Manpower iii. Cost iv. Funding
4. Project management		
5. Decommissioning activities	3. Site and environmental status	i. Site status ii. Environmental status iii. Radiological characteristic
6. Surveillance and maintenance	4. Decommissioning strategy and method	i. Decommissioning strategy ii. Decommissioning method and schedule
7. Waste management	5. Design characteristics and measures for ease decommissioning	i. Design characteristics ii. Action plan
8. Cost estimate and funding mechanisms	6. Safety assessment	i. Radiation risk assessment ii. Risk assessment
9. Safety assessment	7. Radiation protection	i. Apply ALARA ii. Radiation protection design characteristic iii. Dose assessment iv. Radiation protection plan
10. Environmental assessment	8. Dismantlement and decommissioning activities	i. Dismantlement activity ii. Decommissioning activity
11. Health and safety	9. Radioactive Waste management	i. Radioactive waste classification ii. Radioactive waste management during operation iii. Radioactive waste management in decommissioning process
12. Quality assurance	10. Environmental impact assessment	i. Environmental monitoring before decommissioning ii. Environmental monitoring during decommissioning iii. Influence on nearby residents
13. Emergency planning	11. Fire protection	i. Fire Protection
14. Physical security and safeguard	12. Reference	i. Reference
15. Final radiation survey		

Table 9. Decommissioning Environmental Impact Assessment Related Nuclear Act

Nuclear Safety Act	Regulations on technical standards such as reactor facilities
Article 103 (Feedback from residents). ① Provide a draft of radiological environmental impact assessment report or make public hearings. ② Provide a draft of the decommissioning plan or make public hearings.	Article 85-16 (Decommissioning Environmental Impact Assessment). ① The operator shall evaluate the expected radiological environmental impact assessment due to the decommissioning of the reactor facility. ② The operator shall establish and implement an environmental monitoring plan before and during decommissioning of the reactor facilities.

Table 10. Contents to be described in Environmental Impact Assessment for Decommissioning

Items	Contents
Pre-Decommissioning Environmental Survey Plans	• Organization and responsibilities • Site characteristics • Analytical radionuclide • Measurement and analysis of environmental radiation and radioactivity • Selection of sample type and collection point detection target value
Environmental Survey Plans during Decommissioning	• Outline of environmental radiation and radioactivity survey plan around NPP • Space dose rate measurement plan • Space direct dose measurement plan • Land surveillance plan • Marine surveillance plan
Impacts on Nearby Residents	• Exposure scenarios from decommissioning i. Exposure pathways from liquid effluents ii. Exposure pathways from gaseous effluents iii. Direct exposure from NPP • Maximum individual dose at EAB and collective dose of public within domain (normally 80 km) Assessing impacts on existing operational nuclear facilities

No. 2014-12 “Regulation on the Radiation Environment Survey and Radiological Environmental Impact Assessment around Nuclear Facilities” [11], and can be prepared by referring to the environmental impact assessment report for operation permit of nuclear facilities. The contents can be represented for three steps as shown in Table 10, and Table 11 is the result of the draft of domestic decommissioning radiological environmental impact assessment.

4.3 Consideration of Exposure Pathways

The exposure pathways of residents due to decommissioning of nuclear facilities are divided into gaseous effluents, liquid effluents and direct exposure from the NPP. Gaseous effluents are floated in the air or deposited on crops, surfaces, and water, depending on their physical and chemical characteristics. The main gaseous exposure pathways are contaminated air, external exposure from the soil, ingestion of contaminated agricultural and animal products, and internal exposure by inhalation of contaminated air. In addition, the process of ingesting contaminated groundwater that is permeated by radioactive material may be an important exposure pathway. Exposure pathways for liquid effluents include external exposures from contaminated seawater and beaches, internal exposures due to ingestion of contaminated aquatic products. Computer program codes such as ENDOS, TED II, Visual Shield and MCNP can be used for dose assessment based on the operation of nuclear facilities. The impact of decommissioning on residents could also apply the same exposure pathways.

Table 11. Decommissioning Radiological Environmental Impact Assessment Items

Items	Sub Items
1. Pre-Decommissioning Environmental Monitoring	• Describe the pre-decommissioning environmental monitoring plan that is the basis for environmental impact assessment during decommissioning of nuclear facilities • Technical details such as measurement location, period, method, and procedure for each item shall be described with reference to the relevant of the NSSC Notice No. 2014-12, " Regulation on the Radiation Environment Survey and Radiological Environmental Impact Assessment around Nuclear Facilities"
1.1. Organization and Responsibility	• Describe the organization and responsibility to conduct environmental surveys and environmental impact assessments
1.2. Site Characteristics	• Describe the characteristics of the facility and site in outline from the point of environmental survey
1.3. Analysis Nuclide	• Determine analytical nuclides considering the radioactive level of the nearby environment and the accumulation tendency of the radioactive environment due to the operation of the nuclear power plant
1.4. Measurement and Analysis of Environmental Radiation	• Describe the types and characteristics of instruments for measuring radiation and radioactivity, measurement methods and procedures
1.5. Selection of Sample Type and Collection Point	• For radioactivity measurements, describes the methods such as sample collection, preprocessing, analysis, and reliability verification of measurement results, and set and describe the detection target value of the survey item.
1.6. Detection Target Value	• The detection target value shall be set to the lower limit of detection (Annex 2) of the NSSC Notice No. 2014-12, "Regulation on the Radiation Environment Survey and Radiological Environmental Impact Assessment around Nuclear Facilities"
2. Environmental Monitoring During Decommissioning	• Describe the environmental monitoring plan during decommissioning of nuclear facilities for environmental items that will be affected by the decommissioning of nuclear facilities, based on the pre-decommissioning environmental monitoring plan • Technical details such as measurement location, period, method, and procedure for each item shall be described with reference to the relevant of the NSSC Notice "Related Regulations of Radiation Environment Survey and Radiological Environmental Impact Assessment Survey around Nuclear Facilities"
3. Impact on Nearby Residents	• Describe exposure scenarios that take into account all potential exposure pathways caused by radioactive effluents from nuclear decommissioning processes. • Calculate and describe the annual maximum personal exposure dose of the whole body, thyroid, and other major organs that will be received by an individual located on the boundary of the restricted area by the radioactive effluent generated during the decommissioning process of the nuclear facility. • Describe the source term, model, assumptions and input data used in the calculation of the exposure dose. • In case of the occurrence of radioactive effluents due to the operation of multiple nuclear facilities in the same site, the evaluation should include the effects of existing nuclear facilities.
3.1. Exposure Pathway	• Describe the Impact of nearby residents on Radioactive effluents released into the environment due to decommissioning
3.2. Exposure Dose Evaluation (During Decommissioning)	• Assessment of exposure dose to humans should be based on the model and methodology set out in the U.S NRC Regulatory Guide 1.109.
3.2.1. Exposure by Gaseous Pathways	• The exposure through the gaseous pathway is divided into individual dose assessment and collective dose assessment • To prevent environmental harm, absorbed dose, effective dose and organ dose equivalent due to beta rays and gamma rays in air are described on the basis of the standard values in the NSSC Notice No. 2016-16, "Radiation Protection Standards"
3.2.2. Exposure by Liquid Pathways	• The exposure through the liquid pathway is divided into individual dose assessment and collective dose assessment • To prevent environmental harm, effective dose and organ dose equivalent dose should be described on the basis of the standard values in the NSSC Notice No. 2016-16, "Radiation Protection Standards"

3.2.3. Direct Exposure	• After calculating the exposure dose of radioactive material and radiation received by the residents from the facility, compare with reference value and evaluate. In this case, the residents' radiation dose calculation program must reflect the site characteristic and the nearby environmental factors, and the reliability of the evaluation model must be secured. (Consider inside transportation)	
3.2.4. Dose Assessment in Operation Multiple Nuclear Facilities	• In the case of operation a large number of nuclear facilities in the same areas, describe evaluate the effect of radiation by all facilities and confirm whether satisfying the dose standard value at site boundary.	
3.2.5. Summary of Exposure Dose	• Comply with the NSSC Notice No. 2016-16, "Standards on Radiation Protection"	
3.3. Evaluation of Exposure Dose in Case of Abnormal Events	• Nuclear Fuel Accident	- Spent Fuel Handling Accident - Loss of Spent Fuel Pool Cooling - Loss of Water from Spent Fuel Pool - Loss of Offsite Power - 100% Fuel Failure - Criticality
	• Decontamination Accident	- Large Package Handling Accident - Decontamination related Accident - Dismantlement related Accident - Melting Accident
	• Leakage Accident	- Small Leakage Accident outside the Containment Building - Radioactive Waste System Leakage Accident - Fission Product Leakage into the Primary System
	• Fire Accident	- Accident that may be caused by fire
	• External Accident	- Earthquake - Typhoon - Etc
	• Transportation Accident	- Cask or Heavy Load Handling Accident
3.4. Evaluation of Exposure Dose After Site Restoration	• Describe the annual maximum dose to be received by an individual in the restored site through each pathway after completion of site restoration. • Describe the model and input data used in the calculation.	

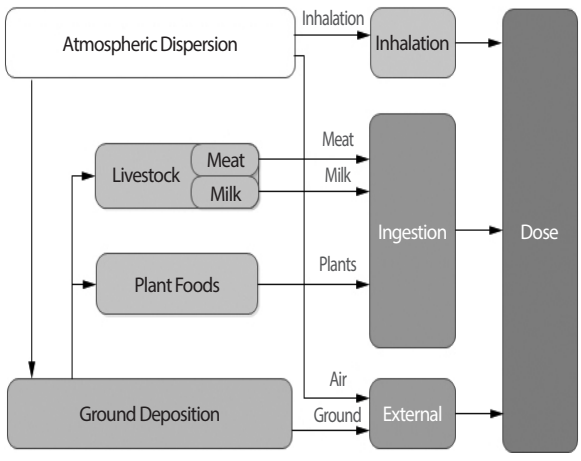

Fig. 4. Exposure Pathway from Gaseous Effluents.

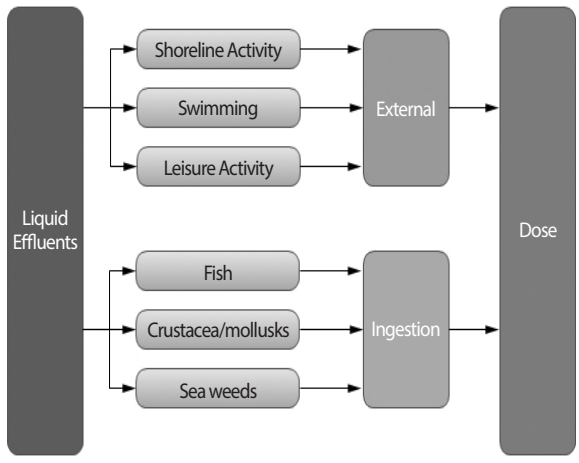

Fig. 5. Exposure Pathway from Liquid Effluents.

However, it is necessary to evaluate the source term that is generated from the decommissioning activities. Fig. 4 and 5 show the exposure pathway through effluents.

4.3.1 Gaseous Pathways

Exposure by gas phase emissions is divided into individual dose and collective dose assessments. In each assessment, there are four exposure pathways such as external exposure due to polluted air, external exposure due to contaminated ground surface, internal exposure due to inhalation, and food intake should be evaluated.

4.3.2 Liquid Pathways

Exposure by liquid phase emissions is divided into individual dose and collective dose assessments. In each assessment, external exposure due to maritime activities (beach activities, swimming or aquatic activities), and internal exposure due to ingestion of aquatic products should be evaluated.

5. Conclusion

Starting with Kori Unit 1, the decommissioning of domestic nuclear power plants is expected to start in earnest. In Korea, Nuclear Safety Act article 103 stipulates that a draft radiological environmental impact assessment report or a decommissioning plan should be made when you making a decommissioning plan. However, domestic regulations only provide general items of DP and radiological environmental impact assessment. Because of this, there is a high possibility that the decommissioning operator will have difficulty in preparing the decommissioning radiological environmental impact assessment. Therefore, this study compares and analyzes of the U.S. related guidelines that have many experiences of decommissioning nuclear power plants, and developed a decommissioning radiological environmental impact assessment (draft) suitable for Korea. First of all, the documents related to the radiological environmental impact assessment during the decommissioning of the U.S. and the evaluation items were reviewed. In addition, the domestic nuclear laws, regulations and existing radiological environmental impact assessments have been reviewed to describe issues to be considered gaseous and liquid pathway in decommissioning. Considering all these factors, we have developed radiological environmental impact assessment (draft) for decommissioning. In this study, it is considered that radiological environmental impact assessment (draft) developed could serve as a stepping stone for the decommissioning of domestic nuclear power plants.

Acknowledgments

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REFERENCE

[1] Ineternational Atomic Energy Agency, “Decommissioning of Facilities Using Radioactive Material, Safety Requirements No.WS-R-5”, October 2006.

[2] International Atomic Energy Agency, “Standrad Format and Content for Safety Related Decommissioning Documents, Safety Report Series No.45”, July 2005.

[3] NUREG-0586, “Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities”, NRC, November 2002.

[4] United States Nuclear Regulatory Commission, “10CFR 50.82 Termination of License”, August 2017.

[5] Dominion Engergy Kewaunee, “Kewaunee Power Station Post-Shutdown Decommissioning Activities Report”, February 2013.

[6] Sacramento Municipal Utility District, “Rancho Seco Post-Shutdown Decommissioning Activities Report”, July 2003.
[7] Duke Energy, “Crystal River Unit 3 - Post Shutdown Decommissioning Activities Report”, December 2013.
[8] Nuclear Safety and Security Commission, “Regulations on Technical Standards such as reactor facilities”, NSSC, June 2016.
[9] Nuclear Safety and Security Commission, “Regulation for the Preparation of Nuclear Decommissioning Plans”, NSSC Notice 2015-8, July 2015.
[10] Nuclear Safety and Security Commission, “Standards on Radiation Protection”, NSSC Notice 2016-16, August 2016.
[11] Nuclear Safety and Security Commission, “Regulation on the Radiation Environment Survey and Radiological Environmental Impact Assessment around Nuclear Facilities”, NSSC Notice 2014-12, November 2014.