Safety Assessment for Decommissioning Worker

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Abstract. Nuclear power plants have a licensed lifetime. Nowadays, as the number of globally aged nuclear power plants increases, the need for research on the decommissioning of nuclear power plants is increasing. Unlike the decommissioning of other infrastructures, the decommissioning of nuclear power plants has a risk of radiation. Therefore, safety evaluation of dismantling worker about radiation is required. This study proposes a framework for evaluating the safety of workers during the decommissioning process of nuclear power plants and conducted a case study on Kori nuclear power plant unit 1 based on the proposed framework. It is expected that the risk information obtained from the evaluation can be used for developing a guideline for the dismantling worker to minimize potential risk.

Keywords: Nuclear power plant · Decommissioning worker
Safety assessment · Human error

1 Introduction

Recently, researches on the decommissioning of nuclear facilities have become active due to the end of nuclear power plant operating license. It is expected that there will be a large number of globally aged nuclear facilities (nuclear power plants, research reactors, nuclear fuel circulation facilities, etc.). Unlike the dismantling of other buildings, the dismantling of a nuclear power plant has a radiation risk. There also has little experience in decommissioning nuclear facilities. Since there is a risk of radiation, safety evaluation of workers dismantling nuclear power plants is necessary. Therefore, proper planning, assessment and case study should be conducted in order to safely carry out decommissioning activities [1].

Radiological hazards exist in the dismantling process of nuclear power plants.

Therefore, in dismantling nuclear plants, workers should be protected, and accidents should be prevented. In addition, a new systematic safety assessment to reduce the radiological risk of decommissioning is needed.

Through this study, a framework for safety assessment of workers was presented. This framework is used to derive radiological risks for workers in the radioactive area. It also provides guidelines for reducing risk.

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By performing safety evaluation according to the proposed framework, it will be possible to secure the safety of workers in decommissioning situations and prepare for accident scenarios.

2 Safety Assessment Framework

A safety assessment framework should be developed with a systematic approach to deriving potential hazards of decommissioning of nuclear facilities and possible accidents of decommissioning activities. In this work, to propose a safety evaluation procedure framework as shown in Fig. 1, the report of IAEA's "Safety Assessment for Decommissioning" was referred.

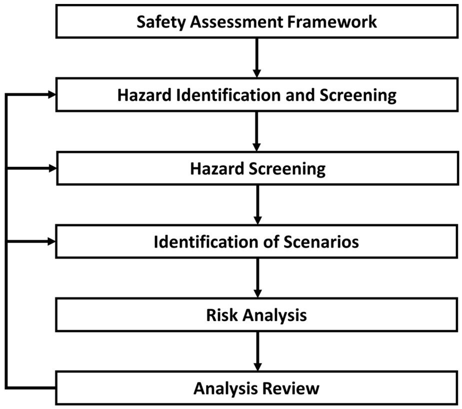

Fig. 1. Safety assessment framework

These safety assessment procedures should be used to assess potential hazards and doses during the decommissioning process and to compare the effective dose and risk with safety standards. The results (effective doses or risk factors) should also meet regulatory safety requirements, taking into account the safety assumptions, such as time, goal of the disassembly procedure step by step.

In order to evaluate the safety, a safety assessment approach (deterministic/probabilistic, conservative, etc.) should be used to derive the risk of decommissioning process [1, 2].

2.1 Hazard Identification

The hazard identification process should identify all areas where radioactive materials may be present, such as radioactive material, waste accumulations, surface and floor contamination, ventilation system and filters, etc., Consideration should be given to the possibility that radioactive material and dust may accumulate in the work area due to continuous decommissioning procedure.

The hazard identification process begins with an analysis of all possible potential initiating events.

2.2 Hazard Screening

During the decommissioning procedure, the risk factors are selected using the initial events in 2.1 information above. The screening process should take into account any potential exposure pathways that could harm workers working in the work area. Therefore, it is necessary to continuously analyze new pathways of exposure through continuous research. For example,

– direct emission of gamma emission nuclides of radioactive concrete
– contamination, external exposure from radioactive structures
– Internal exposure by dust of radioactive structure
– Combination of radiological contamination and personal injury (fall, collision etc.)

In this study, human error analysis through Hazard and Operability (HAZOP) and Mechanical error analysis through Failure Mode & Effect Analysis (FMEA) are qualitatively performed to find the path of exposure and risk factors.

2.3 Identification of Scenarios

As shown above, a list of several accident scenarios should be made taking into account the initial events, hazards and exposure pathways. It should also be analyzed in the normal case of the existing decommissioning work procedures as well as the accident scenarios. In order to derive accident scenarios, human error analysis and mechanical error analysis are used in the process steps derived from HAZOP and FMEA during the Hazard Screening phase. The accident scenarios are derived from the industrial accident cases investigation.

Accident scenarios require repeated analysis and validation of initial event identification, exposure pathways, and accident scenarios since more pathways and risk factors may be present than were initially identified (Fig. 2).

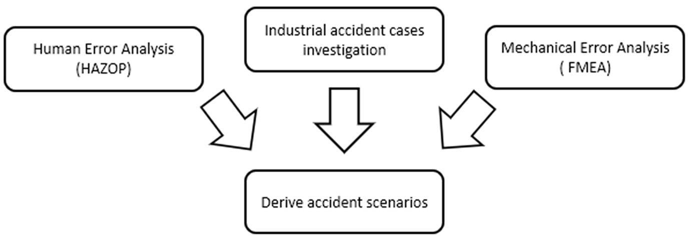

Fig. 2. Identification of scenario process

2.4 Risk Analysis

Risk analysis is to quantify the radiologic results of the workers for normal and accident scenarios. In other words, effective dose and risk should be calculated and evaluated by introducing normal, accident scenarios, decommissioning procedures, and radioactivity concentration to the probabilistic model. In addition, worker exposures in accident scenarios should be calculated and compared to the baseline, if the exposure exceeds the baseline, prophylactic and additional measures should be developed to reduce the consequences.

In this study, nuclide analysis is performed using MCNP [6], and VISIPLAN [7] is used to evaluate worker exposure. This study develops a quantitative model of accident scenarios through frequency analysis of derived accident scenarios. Also, a worker's guidebook is proposed to reduce the risk of workers during dismantling process through risk analysis.

3 Method

3.1 Hazard and Operability (HAZOP)

A systematic approach is needed to systematically derive human error. By introducing basic guidelines on this, it is possible to consider all possible human errors in a systematic way. HAZOP derives human errors in the process using guide words and human action factors. The guide words are introduced to take all possible deviations into consideration and is a total of 7 guide words.

The guide words are shown in Table 1 below. The guide words in Table 1 indicate that there is 'No', 'Not' to derive a situation where no action occurred, and the 'More' that leads to a situation in which a lot of actions occurred, 'Less' that results in less activity or rare occurrence. The 'Part of' that leads to a partial action. 'As well as', a situation that adds behavior. The 'reverse' to derive a situation that reverses the behavior. And finally, the 'other' situation, which does something different about the act. This guide words are used to modify the characteristics human factors and the purpose of analysis.

Table 1. Guidewords of HAZOP

Guide words
No, Not, Node
More, High, Large, Fast
Less, Low, Small, Slow
Part of
As well as
Reverse
Other than

The factors of human error are derived by combining the guide words of Table 1 and the human action factors of Table 2. For example, a combination of 'catch' and 'not' leads to 'unable to catch', and a possible accident of this action can lead to an accident that 'cannot catch a safety railing' [4].

Table 2. HAZOP human action factors

	Human action factors		Human action factors
Hand motion	Catch/grasp/support	Foot Motion	Slip/Fall
	Pull		Bright
	Push/erect		Kick
	Press down	Body Motion	Stand
	Stretch		Sit
	Touch/Contact		Bend
	Stroke		Spread out
	To Wipe		Back
	Lift		Lay down
	Set/Lower		Kneel down
	Turn		Cover
	Shake		Wear
	Throw		Take off
	Stab		Walk
	Wield		Run
	Hit		Lean
	Insert		Jump
	remove		Tremble/Shake/Keep
	Combine/Assemble		
	Separation/Disassembly/Release		
	Tilt		
	Reverse		
	Tumble		
	Scratch		
	Bet		
	Turn on		
	Turn off		

3.2 Failure Mode and Effect Analysis (FMEA)

Fault Mode and Impact Analysis (FMEA) is a method of deriving fault sources for a system or device. When a failure occurs in a device or a part, the effect of the failure on the system is analyzed to derive a device or part that has a great influence. Measures can be taken against equipment or components for which the risk has been derived, improving the availability, reliability or quality of the system. The purpose of the FMEA is to derive the mode, cause and effect of the potential failure of the equipment and to provide a solution to reduce or eliminate the occurrence of accidents, hazards and potential failures during the decommissioning process.

It is analyzed by the process shown in Fig. 3 below. First, the required equipment is selected, and the failure mode of the equipment is predicted, and the effect of the failure of the equipment is analyzed. It is possible to draw out the accidents [5].

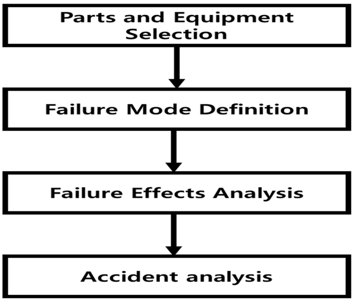

Fig. 3. Failure mode & effect analysis process

3.3 Event Tree Analysis (ETA)

The event tree method is a technique for qualitative and quantitative risk assessment of the final results arising from the initial events of the worker and elements of equipment.

Event tree is a method widely used in probabilistic safety assessment (PSA), which is often used for plant safety evaluation. This study is used for risk analysis using frequency analysis and worker exposure assessment [1].

4 Case Study

In this study, safety assessment of bioshield decommissioning process was performed. The bioshield is one of the characteristics of power plants. It is a concrete that prevents radiation from the core, so it is the concrete that exist radioactive material the most. This study assessed risks to derive radiologic risks to workers during the bioshield decommissioning process (Fig. 4).

The above safety framework is applied with the decommissioning scenario. The decommissioning scenario has been simplified and also derived from the research decommissioning scenario which is decommissioning KRR 1 & 2 [3]. Evaluate using Kori unit-1 bioshield decommissioing. Concrete decommissioning procedures were divided into preparation phase, cutting phase, drilling phase, and transportation phase. Also, the exposure was evaluated at 300, 800, and 1300 cm height.

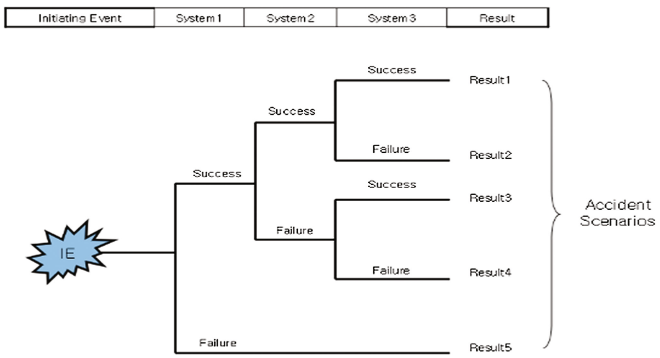

Fig. 4. Event tree analysis example

4.1 Human Error Analysis Result Using HAZOP

In the work step of the decommissioning procedure, Error factors is created by combining the guidewords of HAZOP and human factor action. Predictable accidents and risk factors is also derived. The following Table 3 is a part of the result of the analysis.

Table 3. Human error analysis example.

Work step	Details activities	Error factor	Predictable accident	Risk factors
3.5 Perform drilling using a piercer	3.5.1 Carrying the perforator	Push back	When carrying perforator, it cannot be pushed well, the worker is laid	
	3.5.2 Perforations are used to puncture the concretes	Not catch	When puncturing, hold the perforator weakly to fit the radioactive debris.	Flying, External exposure
3.6 Insert the wire into the perforated hole and fix the wire by operating the crane hook.	3.6.1 Insert wire into perforated hole	Only partly	Damage to fittings and protective equipment due to radioactive debris by hanging part of wire	Falling, Flying, External exposure, Internal exposure
	3.6.2 Moving the crane near the perforated hole	Press another	Crane operator improperly manipulated and impacted by radioactive concrete and damaged protective equipment.	Collision, External exposure, Internal exposure

(*continued*)

Table 3. (*continued*)

Work step	Details activities	Error factor	Predictable accident	Risk factors
	3.6.3 Fixing the wire by operating the crane hook	Only partly	Damage to fittings and protective equipment caused by radioactive debris by hanging part of the wire.	Falling, Flying, External exposure, Internal exposure
3.7 Install diamond wire saw in working area	3.7.1 Carrying diamond wire saw	Push back	Cannot push it well when carrying wire saw, the worker laying down.	Inversion, External exposure
	3.7.2 Installation of diamond wire saws			

4.2 Mechanical Failure Analysis Result Using FMEA

In the work step of the decommissioning procedure, failure modes and effects analysis were used to derive potential failure effects and possible accidents in the event of failure of equipment, parts and equipment. And analyzed as shown in Table 4 below.

Table 4. Mechanical error analysis example

Details activities	Potential failure mode	Predictable accident	Potential failure effects
1.3.1 Protective clothing and mask preparation	Defective protective equipment	Defective clothing and mask defective rate and bad condition not checked.	External exposure, Internal exposure
3.5.2 Perforations are used to puncture the concretes	Equipment defect	Damage to objects and protective equipment due to radioactive debris from equipment failure	Flying, External exposure, Internal exposure
3.6.2 Moving the crane near the perforated hole	Crane operating equipment damage	Crash of malfunctioning crane and operator and damage to protective equipment	Collision, External exposure, Internal exposure
3.6.3 Fixing the wire by operating the crane hook	Only partly	Damage to fittings and protective equipment caused by radioactive debris by hanging part of the wire	Falling, Flying, External exposure, Internal exposure
3.7.1 Carrying diamond wire saw	Push back	Cannot push it well when carrying wire saw, the worker laying down.	Inversion, External exposure
3.7.2 Installation of diamond wire saws			

4.3 Accident Scenario Example

The possible accidents during the dismantling process were derived through the previous safety assessment framework. Possible accidents during the dismantling process include accidents caused by mechanical errors, accidents caused by human errors, and accidents caused by natural disasters.

In the event of an accident caused by a mechanical error affecting internal exposures, such as a failure of the mask, a failure of the dust absorber, or a failure of the ventilation system, the failure of the crane, Falling, collapsing, falling, laying on, getting stuck on an object, pinching, cutting, piercing, fire, or electric shock. Among them, it is difficult to evaluate workers' exposure to accidents caused by natural disasters.

4.4 Risk Assessment Quantification Model Example

As an internal exposure accident scenario, the accident scenario was analyzed considering the failure or operation of the mask, the failure or operation of the ventilation system, and the failure or operation of the dust absorber. Exposure assessment was performed in consideration of dust absorption rate, ventilation system, and failure or operation of the mask in internal exposure evaluation equation and VISIPLAN. Also, in case of dust that should be considered in the internal exposure, it will occur only in cutting operation. Therefore, the internal exposure evaluation was carried out based on 1 h of cutting time.

Table 5 shows the results of evaluating the internal exposure in the mask accident scenario. S indicates that the component is operating normally, and F indicates a malfunction. The sequence first means that this mask is malfunctioning or working, the second is when the ventilation system is failed or worked, and the last time this dust absorber is failed or worked.

Table 5. Internal exposure in mask accident scenarios

Height/Scenario(mSv)	300 cm	800 cm	1300 cm
SSS	9.24E−12	1.92E−22	1.37E−33
SSF	9.24E−10	1.92E−20	1.37E−31
SFS	2.31E−08	4.80E−19	3.42E−30
SFF	2.31E−06	4.80E−17	3.42E−28
FSS	9.24E−08	1.92E−18	1.37E−29
FSF	9.24E−06	1.92E−16	1.37E−27
FFS	2.31E−04	4.80E−15	3.42E−26
FFF	2.31E−02	4.80E−13	3.42E−24

In the following figure, Risk is obtained by using Event Tree using AIMS which is a PSA evaluation tool. Since there is no failure frequency data on the equipment used for dismantling, the failure frequency data is assumed based on the failure data of the equipment used in the nuclear power plant (Fig. 5).

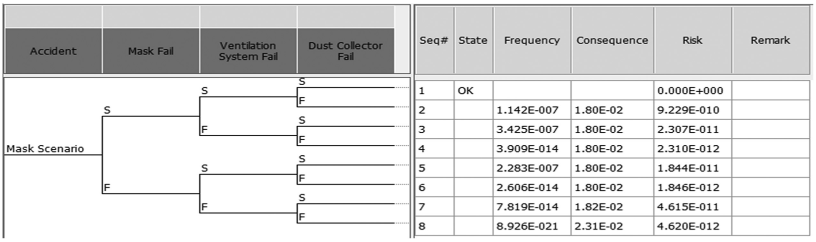

Fig. 5. Risks using AIMS and Event Tree in case of internal exposure accident scenario

As seeing the Table 6, when the height is 800 cm or 1,300 cm, the amount of internal exposure is negligible, irrespective of whether the component is malfunctioning or not. In the evaluation of the 300 cm point with the highest radiation level, the internal dose of the worker is 9.24E−12 mSv in case of no failure of the tool and the equipment (SSS). However, when all of the masks, ventilation systems, and dust absorbers fail (FFF), it is 2.31E−2 mSv, which is non-negligible.

Table 6. Internal and External exposure during mask accident scenarios

Height/Scenario(mSv)	300 cm	800 cm	1300 cm
SSS	1.80E−02	4.30E−03	7.70E−04
SSF	1.80E−02	4.30E−03	7.70E−04
SFS	1.80E−02	4.30E−03	7.70E−04
SFF	1.80E−02	4.30E−03	7.70E−04
FSS	1.80E−02	4.30E−03	7.70E−04
FSF	1.80E−02	4.30E−03	7.70E−04
FFS	1.82E−02	4.30E−03	7.70E−04
FFF	4.11E−02	4.30E−03	7.70E−04

The above results are the result of evaluating the amount of exposure to failure. In order to evaluate the risk of the operator, the frequency of each case should be considered and evaluated. The risk of the mask accident scenario was rated at 1.02E−09 mSv/h. In case of no accidents, it is extremely low to 5.66E−06% compared with 1.80E−02 mSv/h, which is the worker exposure.

4.5 Worker Guideline

The risk information derived using the framework can be used on the operator guideline development. As an example, dose evaluation based on distance is performed in the table above. Derive the distance that the operator should work and, if an accident occurs, derive the guideline for the rescue route of the rescue team. As a guideline, the worker works under 1 m. The rescue worker goes to the rescue work using the weighting machine at less than 1 m (Table 8).

Table 7. Dose assessment by distance from bioshield

	1 m	1.5 m	2 m	2.5 m	From bioshield
3 m	1.82E−02	1.90E−02	2.10E−02	2.10E−02	
8 m	3,10E−03	3.70E−03	4.10E−03	4.30E−03	
13 m	6.20E−04	6.80E−04	7.30E−04	7.70E−04	
Height					mSv/h

Table 8. Yearly and daily possible working time

	Maximum exposure	Minimum exposure
Dose Rate(mSv/h)	0.021	0.018
Yearly Possible Working Time(h/y)	952	1111
Daily Possible Working Time(h/d)	3.2	3.7

The annual radiation dose of radiation workers shall not exceed 20 mSv. If a worker work at a distance of 1 m, which is the minimum exposure, he will receive 0.018 mSv/h as shown in the Table 7, and the workable time will be 1111 h. Assuming that the worker can work around 300 days a year, the daily work time will be about 3 h and 40 min. As seeing the Table 6, If all three devices related to the internal exposure are out of order, over 2 h will exceed the daily dose. As another guideline, the internal exposure accident scenario results suggest that a check is made every 2 h in case three failures occur.

5 Conclusion

Assessment of exposure to nuclear power plant decommissioning process is very important for the safety of workers. In addition to the amount of worker's exposure in normal decommissioning work, it is also necessary to evaluate the risk of the worker when an accident occurs during decommissioning process. Therefore, this study aims to develop a system for evaluating the risk of decommissioning work of nuclear power plants and proposed a framework for deriving accident scenarios.

In this study, only one accident scenario was analyzed, but if the comprehensive risk is evaluated in consideration of various accident scenarios, the risk at the time of accident is expected to rise more than this value.

In addition, subjective evaluation by experts using semantic differential or fuzzy theory is often used as a risk evaluation during the actual dismantling process. Risk assessment with a quantitative model through this framework will be a risk assessment that can be further evaluated objectively. By developing worker's guideline based on the results, a guide to minimize the risk of radiation is presented.

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