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Risk assessment framework for decommissioning workers in radioactive areas

HyungJun Kim, Seung Jun Lee*
Ulsan National Institute of Science and Technology, 50, UNIST-gil, Ulsan 44919, Republic of Korea
Khjsky3459@unist.ac.kr sjlee420@unist.ac.kr

1. Introduction

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. [1].

Radiological hazards exist in the dismantling process of nuclear power plants. Therefore, in dismantling nuclear plants, workers should be protected. 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.

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

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.

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. [1,2].

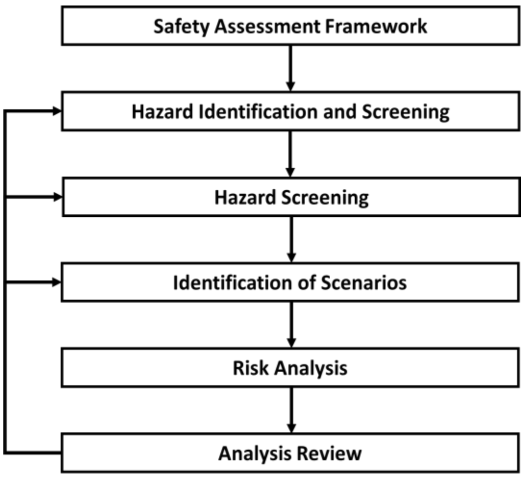

Fig. 1. Safety Assessment Framework

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 consideration 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.

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, and VISIPLAN 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.

Table I: Guidewords of HAZOP

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

This guide words are used to modify the characteristics human factors and the purpose of analysis. Table II. shows the human action factor. There are three major human action factors: hand motion, foot motion, and body motion. It consists of 27 hand motion, 3 foot motion, and 15 body motion.

the factors of human error are derived by combining the guide words of Table I. and the human action factors of Table II. 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 II: HAZOP Human Action Factors

	Human Action Factor
Hand Motion (27)	Catch / grasp / support
	Pull
	Push / erect
	Press down
	Stretch
	Etc.
Foot Motion (3)	Slip / Fall
	Bright
	Kick
Body Motion (15)	Stand
	Sit
	Etc.

3.2. Failure Mode & 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. 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].

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.
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 decommissioning. Concrete decommissioning procedures were divided into preparation phase, cutting phase, drilling phase, and transportation phase.

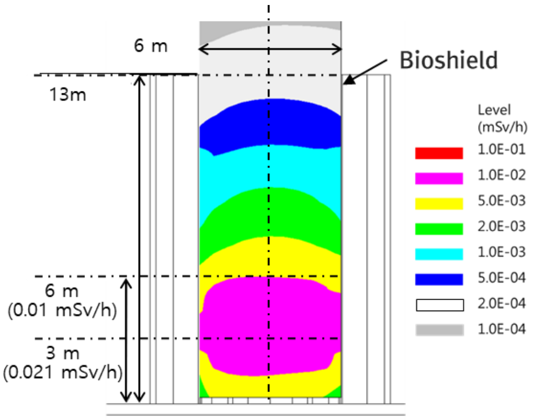

Fig. 2 Dose assessment within bioshield

The annual worker from International Commission on Radiological Protection(ICRP) should not exceed 20 mSv. Assuming 2000 hours per year, it is possible that the area exceeding 0.01mSv / h is more than 20mSv. Therefore, Worker risk assessment for the evaluation of areas under 600cm was conducted.

4.1. 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 this study, the accident scenarios were divided into 4 types according to the method of evaluation of exposure. Table III shows examples of accident scenarios. These accident scenarios were derived through disaster case studies, HAZOP and FMEA.

Table III: Accident Scenario Classification

	Risk
Fall Accident	Crane Fail
	Safety Lever Fail
	Scaffold Fail
	Collision
	Fall from elevation
Narrowness Accident	Crane Fail
	Falling Object
	Narrowness
	Inversion
	Electrical Shock
Cut Accident	Saw Fail
	Cut
	Slippery place.
Internal Exposure	Mask Fail
	Ventilation System Fail
	Dust Collection Fail

4.2. 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 hour of cutting time.

Table IV shows the results of evaluating the internal exposure in the 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 IV: Internal Exposure in Accident Scenarios

Scenario/ Height	600cm	500cm	400cm	300cm
SSS(mSv)	1.22E-12	1.54E-12	9.24E-12	9.24E-12
SSF(mSv)	1.22E-10	1.54E-10	9.24E-10	9.24E-10
SFS(mSv)	3.05E-09	3.84E-09	2.31E-08	2.31E-08
SFF(mSv)	3.05E-07	3.84E-07	2.31E-06	2.31E-06
FSS(mSv)	1.22E-08	1.54E-08	9.24E-08	9.24E-08
FSF(mSv)	1.22E-06	1.54E-06	9.24E-06	9.24E-06
FFS(mSv)	3.05E-05	3.84E-05	2.31E-04	2.31E-04
FFF(mSv)	3.05E-03	3.84E-03	2.31E-02	2.31E-02

Table V: Internal and External Exposure in Accident Scenarios

Scenario/ Height	600cm	500cm	400cm	300cm
SSS(mSv)	1.00E-02	1.37E-02	1.60E-02	1.62E-02
SSF(mSv)	1.00E-02	1.37E-02	1.60E-02	1.62E-02
SFS(mSv)	1.00E-02	1.37E-02	1.60E-02	1.62E-02
SFF(mSv)	1.00E-02	1.37E-02	1.60E-02	1.62E-02
FSS(mSv)	1.00E-02	1.37E-02	1.60E-02	1.62E-02
FSF(mSv)	1.00E-02	1.37E-02	1.60E-02	1.63E-02
FFS(mSv)	1.00E-02	1.38E-02	1.63E-02	1.65E-02
FFF(mSv)	1.30E-02	1.76E-02	3.91E-02	3.93E-02

As seeing the Table IV, at 300cm and 400cm, the internal dose of the worker is 9.24E-12mSv 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-2mSv, which is non-negligible.

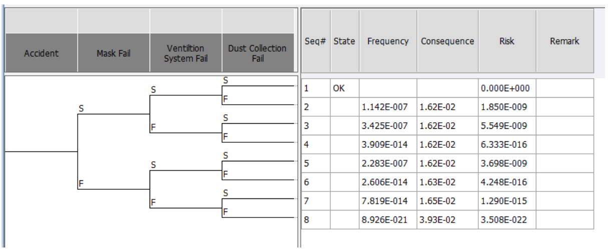

Fig. 3 Risks using AIMS and Event Tree in internal exposure accident scenario

In the above 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.

4.3. Worker Guideline

The risk information derived using the framework can be used on the operator guideline development. The annual radiation dose of radiation workers shall not exceed 20 mSv. If a worker work at a distance of 1 m, he will receive 0.016 mSv / h as shown in the table VI, and the workable time will be 1252 hours. Assuming that the worker can work around 300 days a year, the daily work time will be about 4 hours and 10 minutes.

As seeing the table V, if all three devices related to the internal exposure are out of order, over 2 hours will exceed the daily dose.

The worker's guideline can be derived as follows. It is safe to check the mask, dust absorber, ventilation system every two hours.

Table VI: Yearly and Daily Possible Working Time

Dose Rate(mSv/h)	1.60E-02
Yearly Possible Working Time(h/y)	1252.52
Daily Possible Working Time(h/d)	4.18

Table VII: Dose assessment by distance from Bioshield (Height: 0~600cm)

From Bioshield (cm)	0	50	100	150
Exposure (mSv/h)	1.19E-02	1.20E-02	1.21E-02	1.22E-02
From Bioshield (cm)	200	250	300	-
Exposure (mSv/h)	1.23E-02	1.21E-02	1.10E-02	-

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 at 3m or under 0.5m. The rescue worker goes to the rescue work using the weighting machine at 3m.

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 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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