Safety Assessment Framework for the Nuclear Decommissioning

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Abstract: This study presents and analyzes safety assessment frameworks for nuclear decommissioning process. The safety assessment process for decommissioning will minimize the risks associated with radioactive materials by providing guidance. The guidance ensures safety of workers and the public through the identification of potential risks and mitigating consequences of potential risks. The safety assessment framework is to derive the potential risks of decommissioning nuclear plants and possible accidents of decommissioning activities. It is divided into 4 steps as a safety assessment framework. “Hazard Identification” is the first step of the safety assessment framework. Basically, it is necessary to analyze the initial events that may occur during the decommissioning nuclear process. Step 2 is 'Hazard Screening'. At this stage, a potential exposure routes, could harm workers during the nuclear decommissioning process, should be considered. In order to derive the hazard about decommissioning, human error analysis through HAZOP (Hazard and Operability) and instrumental error analysis through FMEA (Failure Mode & Effect Analysis) are performed considering the paths of the exposure. Step 3 is 'Identification of Scenarios'. This step`s purpose is that making a list of accident scenarios using the hazard derived in the second stage. Step 4 is 'Hazard Analysis'. The final step is to develop probabilistic models for accident scenarios and to calculate worker exposure in accident scenarios to draw preventive and additional actions to reduce consequences [1, 2].

Keyword: Decommissioning, Safety Culture, Safety Assessment Framework

1 Introduction

Recently, researches on the decommissioning of nuclear facilities have become active due to the end of nuclear power life. 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.), and disorganized or planned dismantling facilities. There has little experience in decommissioning nuclear facilities. Therefore, proper planning, assessment and case study should be conducted in order to safely carry out decommissioning activities [1].

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

The safety assessment should develop a systematic approach to deriving potential hazards of decommissioning of nuclear facilities and possible accidents of decommissioning activities. the report of IAEA's "Safety Assessment for Decommissioning " was referred and developed the following safety evaluation procedure framework of Fig. 1.

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 effective time of the hazard. In order to prepare for various accidents, accident scenarios and models for evaluation should be presented [1,2].

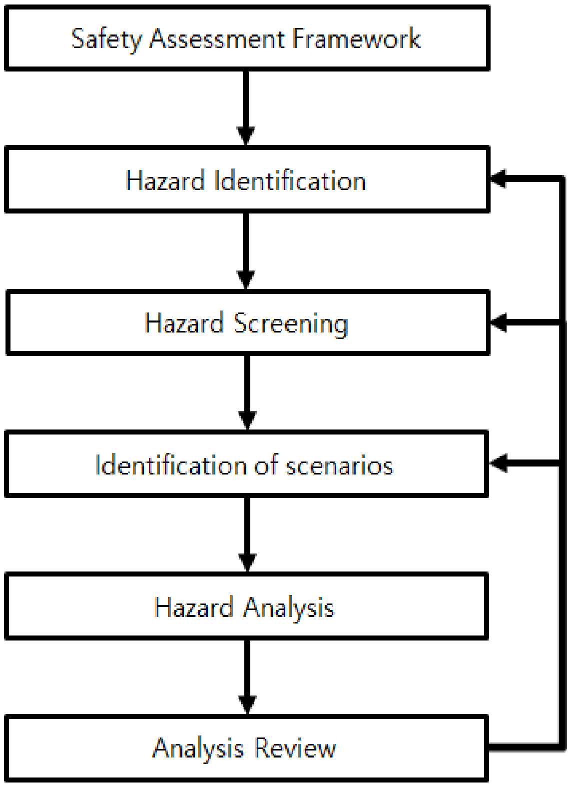

Fig. 1 Safety Assessment Framework

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 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 select 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.

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 Hazard Analysis

Risk analysis is to quantify the radiologic results of the operator 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.

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 1 Guide words of HAZOP

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

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 is used to modify the characteristics human factors and the purpose of analysis.

Table 2 HAZOP Human Action Factors

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

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].

3.2 Failure Mode & Effect Analysis

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. 2 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

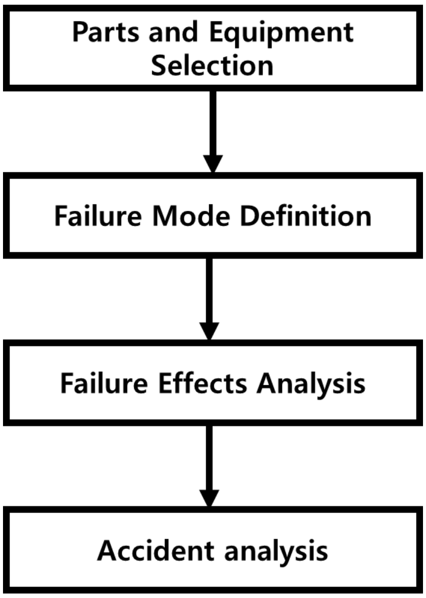

Fig. 2 FMEA Process

is possible to draw out the accidents there.[5]

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.

When an accident occurs at a nuclear power plant, there are several safety systems to prevent accidents from spreading. Event tree analysis is a systematic analysis of how the safety system affects the success or failure of an initial event. [1].

4 Result

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 concrete procedure for decommissioning concrete. 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.

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.

4.2 Mechanical Error 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 3

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
	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			

Table 4

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 Mask Failure Accident Scenario

As a mask failure 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 4 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)	300cm	800cm	1300cm
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

Table 6 Internal and external exposure during mask accident scenarios

Height/Scenario(mSv)	300cm	800cm	1300cm
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

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.

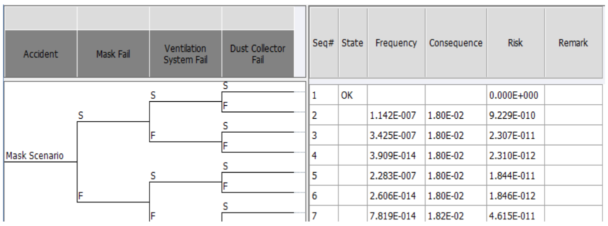

Fig. 3 Risks Using AIM and Event tree in Case of Masking Accident

5 Conclusion and Discussion

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.

As seeing the Table 6, when the height is 800cm or 1,300cm, the amount of internal exposure is negligible, irrespective of whether the component is malfunctioning or not. In the evaluation of the 300cm point with the highest radiation level, 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.

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-02mSv / h, which is the worker exposure.

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.

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