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A Quantitative Assessment for Various Severe Accident Management Strategies

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1. Introduction

After the Fukushima nuclear power plant accident in 2011, safety inspections on all operating domestic nuclear power plants were conducted to confirm the safety of domestic nuclear power plants and to establish various improved severe accident management (SAM) strategies. Accordingly, it became necessary to assess the quantitative effects of post Fukushima SAM strategies and to identify the additional safety countermeasures. Moreover, a single severe accident management strategy could be used independently, but in actual situations, various strategies could be implemented synthetically. Therefore, the quantitative effects of each SAM strategy and their synthetic implementation were evaluated in this study.

2. Methods and Results

2.1 Reference system, SAM strategies and accident scenario

Westinghouse (WH) 3-loop reactor was selected as a reference system. WH 3-loop reactor probabilistic safety assessment (PSA) model has been recently developed and maintained up to date among the PSA models for domestic nuclear power plants [1]. In addition, quality improvement items were reflected in the PSA model and report by performing quality grade evaluation through PSA quality improvement project of WH type nuclear power plant which was carried out from April 2004 to March 2006 for two years. Therefore, WH 3-loop reactor, which maintains the highest quality while reflecting the latest information from the PSA model, was selected as a reference system.

As a reference SAM strategy, the primary and secondary emergency cooling water external injection strategy (EXT), one of post Fukushima SAM strategies, was selected. The EXT strategy could be used to maintain the integrity of the reactor vessel and mitigate the release of radioactive material. The external injection point of the emergency cooling water is at the point of time when the fuel cladding is damaged 50% in the case of the primary system, and after the secondary side of the steam generator is exhausted in the case of secondary system. For external injection, it is necessary to depressurize below the injection head of the pump. Various means could be used to depressurize in the reference system. In the study, it was assumed that the primary system uses a pressurizer pressure relief valve and the secondary system uses a steam generator pressure relief valve.

A filtered containment venting strategy (FCVS) was selected as another reference SAM strategy. The FCVS is to prevent the containment building from being damaged by exhausting non-condensable gas and vapour outside the containment through the filter system, and to capture most of the radionuclides except inert gas to reduce the offsite health effect by the radioactive material [2]. The filtered containment venting system used in this strategy generally provides an effective means to maintain the containment building integrity during severe accidents and to minimize the amount of radioactive material released to the atmosphere. In addition, it limits the emission of aerosols, element iodine to minimize the effect of radiation at the beginning of the accident. However, this strategy should be considered as a last resort as far as possible since it accompanies a certain amount of radionuclide release [3].

Station Blackout (SBO), like Fukushima nuclear power plant accident, was selected as a reference accident scenario. SBO-R scenario means an accident in which the emergency diesel generator fails during operation. Since the SBO causes the loss of function of all containment building safety systems, it is a critical accident scenario for core damage and offsite risk. In addition, the SBO is effective to assess the FCVS, which is a strategy to prevent gradual overpressure of containment building, since many sequences of SBO leading to late containment failure (LCF).

2.2 Plant Damage States

Plant damage states (PDS) were used to reduce the amount of accident analysis to be performed. The PDS is defined as a combination of possible values for each PDS variable such as reactor coolant system (RCS) status and containment safety system status. The purpose of this classification is to reduce the amount of accident analysis that should be performed while maintaining the progress characteristics of the accident by grouping a large number of core damage events into a small number of groups representing similar plant states at the time of core damage. These combinations should be designed to be physically feasible and not conflict with other definitions used in the analysis. The PDS event tree, which is constructed considering the availability of the containment building system, plays a role in linking the level 1 PSA and the level 2 PSA.

In order to evaluate the effectiveness of two SAM strategies for SBO-R scenario, PDS 18, 19, 29, and 30 in figure 1 were analyzed. PDS 18 means that both EXT and FCVS strategies are implemented, PDS 19 means that only the EXT strategy is implemented, PDS 29 means that only the FCVS strategy is implemented, and PDS 30 means that both EXT and FCVS strategies are not implemented. The common characteristics of each PDS are as follows.

- No containment bypass
- Containment isolated
- Low RCS pressure
- In-vessel injection failure

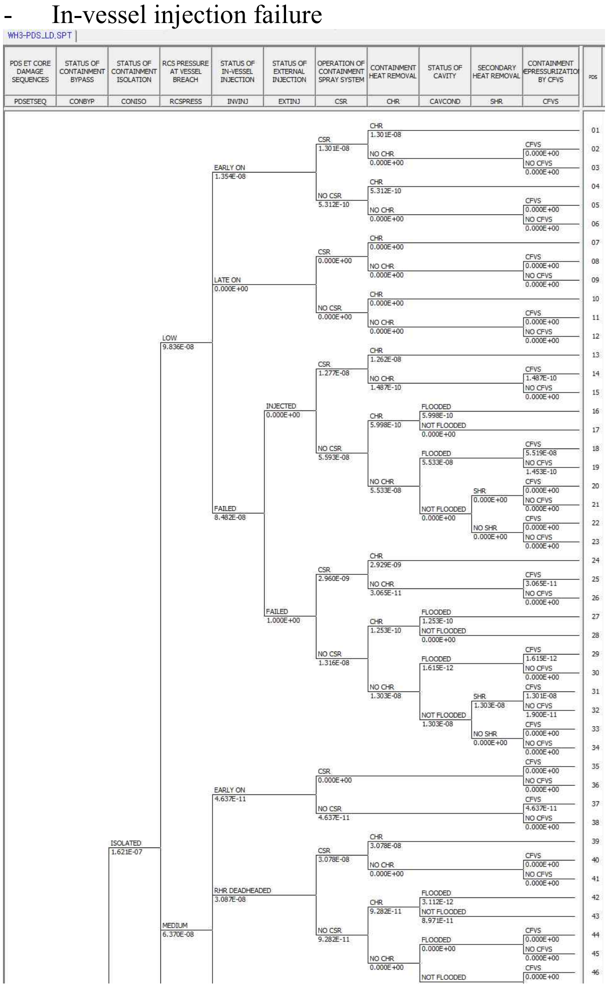

Fig. 1. Plant damage states for station blackout scenario [4].

2.3 Containment Event Trees

In the level 2 PSA, the sequential accident progress of the core damage events confirmed in the level 1 PSA is evaluated including quantitative evaluation of the severe accident phenomenon that occurs after severe damage to the nuclear fuel. The containment event tree (CET) is to analyse the behaviour characteristic of containment, such as containment conditions and type of containment damage that may occur during the progression of severe accidents inside the containment building, by simulating the accident progression sequences so as to evaluate the containment failure frequency [4].

The decomposition event tree (DET) is used to logically determine the branch probability of the CET by identifying the important sub-event that is necessary for the quantification of the CET. Through the CET/DET method, the phenomenon that is important to the accident progression or the type of damage to the containment building is made up of the headings of the CET. This is a simplified method considering the complex severe accident phenomenon in the CET and the operation of the containment building safety system in the DET. The CET for PDS 30, modeled to evaluate the SAM strategy quantitatively, is shown in figure 2.

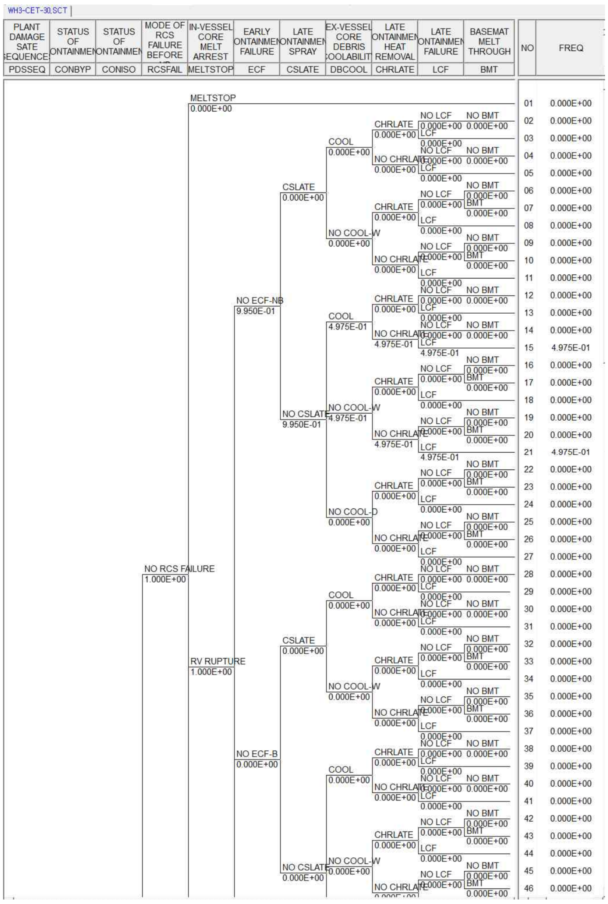

Fig. 2. Containment event tree for plant damage state 30.

2.4 Results

In order to evaluate the effectiveness of each SAM strategy, EXT and FCVS headings were alternately entered in PDS with 0 and 1, respectively. These four PDSs were quantified to CET, and the conditional probabilities of failure mode of CET reflecting each SAM strategy were evaluated. The results of evaluating the quantitative effects of each SAM strategies, the variation of the conditional probability of each failure mode, are shown in table I. The base case means that both SAM strategies are not implemented. In the case of base case and EXT only case, the conditional probability of NO CF, the probability which containment failure does not occur, was evaluated as zero. This means that ECF or LCF will occur. However, when the FCVS strategy is implemented, NO CF probability is increased to 0.9839. Also, when both FCVS and EXT strategies were implemented, NO CF probability was 0.9871, which was higher than that of FCVS only case.

Since the base case does not implement the SAM strategy for the SBO-R scenario, the probability of LCF due to gradual containment building overpressure is dominant. In the case of EXT only, the probability of ECF increased due to the possibility of adverse effect, steam explosion. Since the filtered containment venting system is a countermeasure for containment building overpressure, both the probability of LCF and ECF decreased and the probability of NO CF increased when FCVS was implemented. When both EXT and FCVS were implemented, the probability of NO CF increased more than that of FCVS only case, but the probability of ECF also increased due to the possibility of steam explosion. Therefore, for the selected PDS in this study, the FCVS and Both cases were evaluated as effective accident management strategies in terms of increasing NO CF probability. The quantitative effects of SAM strategies for entire scenario could be assessed by applying this methodology to all PDSs.

Table I: Conditional probability of failure mode of each case

	Conditional Probability			
	Base case	EXT only	FCVS only	Both
NO CF	0	0	0.9839	0.9871
LCF	0.9950	0.4976	0.0109	0.0054
ECF	0.0050	0.5024	0.0052	0.0075

3. Conclusions

As a result of the Fukushima nuclear power plant accident that occurred in 2011, doubts about the safety of nuclear power plant have increased, and public opinion about the risk of nuclear power plant has spread in negative direction. Accordingly, safety inspections on all operating domestic nuclear power plants were conducted to confirm the safety of domestic nuclear power plants and to establish various improved severe accident management strategies. Therefore, assessing the quantitative effects of post Fukushima SAM strategies became necessary.

In this study, the quantitative effects of each SAM strategy and their synthetic implementation were evaluated. As a result of the evaluation, it was confirmed that when the SAM strategies were implemented in a synthetic manner, the effectiveness of SAM strategies had different characteristics in comparison to each single SAM strategy. Using the methodology in this study, the optimum accident management strategies could be evaluated. Furthermore, various strategies in the severe accident management guidelines (SAMG) could be improved by utilizing the methodology.

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