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An Evaluation of Severe Accident Management Strategies Using Level 2 PRA

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1. Introduction

Since the Fukushima accident, various follow-up measures have been implemented for improving a safety of nuclear power plants. Especially, Severe Accident Management Strategies (SAMSs) should be evaluated qualitatively and quantitatively before implementation of it. SAMSs can be evaluated by Probabilistic Risk Assessment (PRA). PRA can provide regulatory institutes and Operators with a risk information of SAMSs. Risk-informed regulation and application are useful to enhance the safety of nuclear power plants.

In this study, we conducted level 2 PRA for a selected reference nuclear power plant in which SAMSs was applied. And, we evaluated a containment integrity for SAMSs. Furthermore, we suggested the quantified results for each initiating events. A goal of this study is to find insights for the effectiveness of SAMSs.

2. Methods and Results

In this section, the base model and its modifications are described. And, the quantification results of it are suggested.

2.1 Selection of base model and SAMSs

2.1.1 Selection of base model

In this study, we selected Westinghouse 3-loops type Pressurized Water Reactor (PWR) model as a base model. The model has 3 loops reactor coolant system type including 3 hot legs, 3 cold legs and 3 reactor coolant pumps. Its main safety systems include High Pressure Safety Injection System (HPSIS), Low Pressure Safety Injection System (LPSIS), Safety Injection Tank (SIT), Pressure Operated Relief Valve (PORV), Containment Spray Injection (CSI), Containment Fan Cooler (CFC), Auxiliary Feed-Water (AFW) system and Essential Chiller Condenser (ECC) system [1].

The Westinghouse 3-loops type PWR has three charging (CHG) pumps and two residual heat removal (RHR) pumps. One of the three CHG pumps acts as a charging pump during normal operation, but after the SI signal, all three CHG pumps act as high pressure safety injection (HPSI) pumps. In addition, the two RHR pumps are on standby during normal operation and serve as low pressure safety injection (LPSI) pumps after the SI signal.

2.1.2 Selection of SAMSs

In this Study, we applied 2 SAMSs into the base model. The first strategy is Cavity Flooding Strategy (CFS). The goal of this strategy is to prevent or mitigate Molten Core-Concrete Interaction (MCCI). If the core debris is cooled outside the reactor vessel by a cooling water pool in the reactor cavity, the MCCI will be prevented. Even if the core debris cannot be completely cooled outside the reactor vessel, it can mitigate the core melt-concrete reaction if there is a cooling water pool in the reactor cavity. And the fission product or hydrogen generated during the MCCI can be reduced considerably, and some of the fission products released can be expected to be cleaned through the cooling water pool. But, there are some adverse effects such as steam explosion outside reactor vessel.

However, the reference nuclear power plant has no cavity flooding system unlike APR 1400. So, we assumed that cavity is flooded by external source such as fire hose. Therefore, the failure probability of CFS depends on only human error. So, we used the probability of 0.41 [2].

The second strategy is Filtered-Containment Venting System (FCVS) strategy. In the situation that internal pressure of containment is increased gradually, it is very effective to reduce pressure by filtered ventilation. But, this strategy also has some adverse effects that noble gases cannot be filtered and it will be released to environment. Another adverse effect is that hydrogen burn can be generated locally by FCVS [3].

2.2 Modification of base model

We modified the base PRA model to evaluate the selected SAMSs. The base model has 24 Plant Damage State Event Trees (PDS ET) for initiating events. For modifying the base model, we made 2 assumptions. The first is that CFS will be performed after SAMGs (Severe Accident Management Guidelines) entry condition. And the second is that FCVS strategy will be performed at containment design pressure. The heading of CFS in the PDS ET was added in the case that LPSIS and containment spray injection system are failed. And, the heading of FCVS was added in the PDS ET when containment heat removal is failed except for failure of containment isolation. All PDS ET cannot be shown in this paper. Only PDS ET for LOOP is shown in Fig. 1.

In the PDS LD, CFS was reflected in the logic of the status of cavity by adding it. In the case of FCVS, it was reflected by adding the heading of it. Thus, the number of PDS ETs is 70. And, it is shown in Fig. 2.

In the Containment Event Tree (CET) and Decomposition Event Tree (DET), we modified the DETs for MELTSTOP and LCF. In the DET for MELTSTOP, the probabilities of MELTSTOP is different whether the FCVS strategy was failed or not. And, in the DET for LCF, we added a heading of FCVS and modified some branches which are shown in Fig. 3.

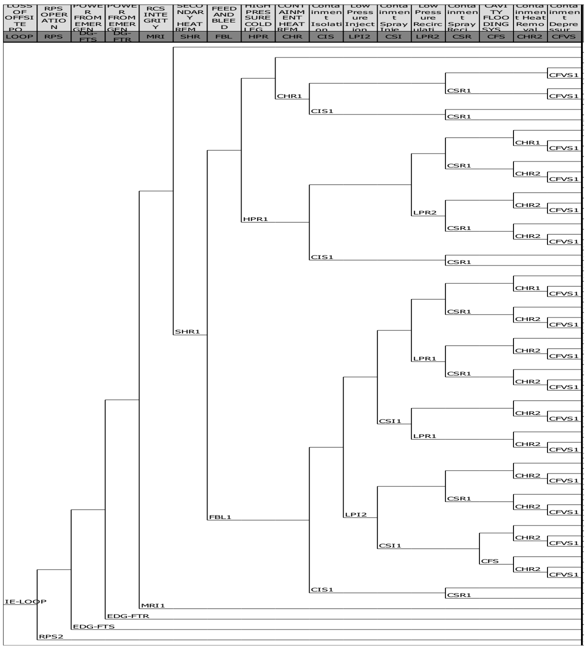

Fig. 1. The modified PDS ET for LOOP

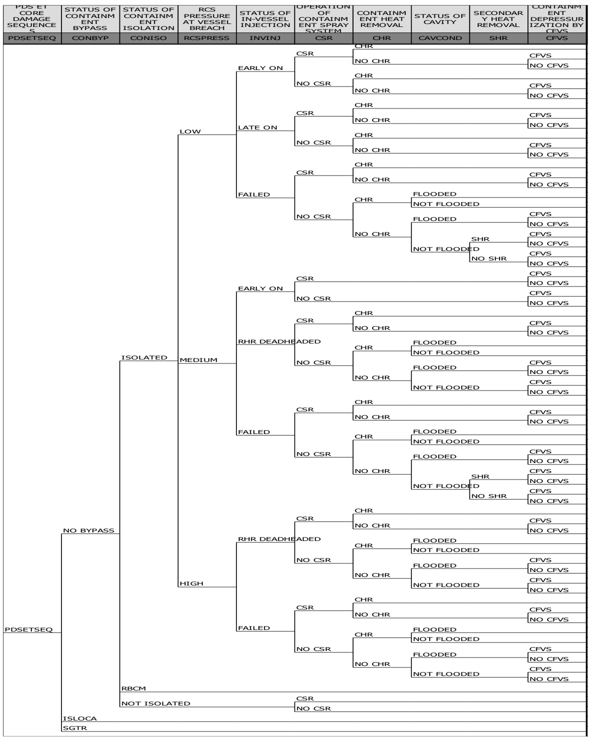

Fig. 2. The modified PDS logic diagram

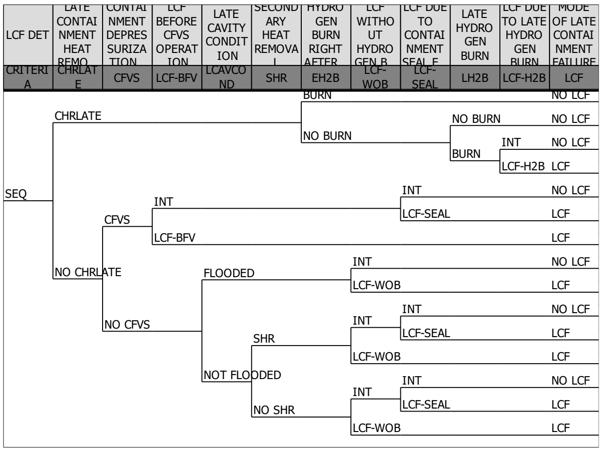

Fig. 3. The modified DET for LCF

2.3 Quantification and Results

Base on the modified base model, we analyzed level 2 PRA. We quantified 4 cases in accordance with implementation of SAMSs. Each quantification results for containment failure are shown from Fig. 4 to Fig. 9. The values in each result are change rate in percent for the model that all SAMSs are not implemented.

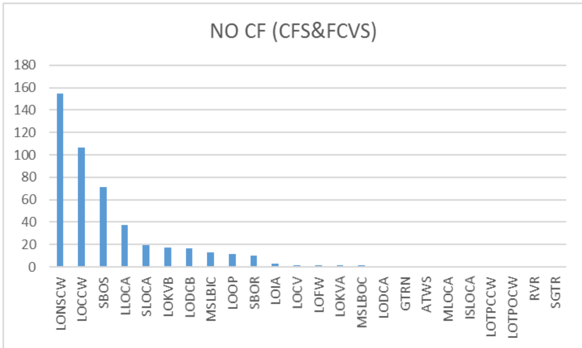

Fig. 4. No containment failure for CFS&FCVS

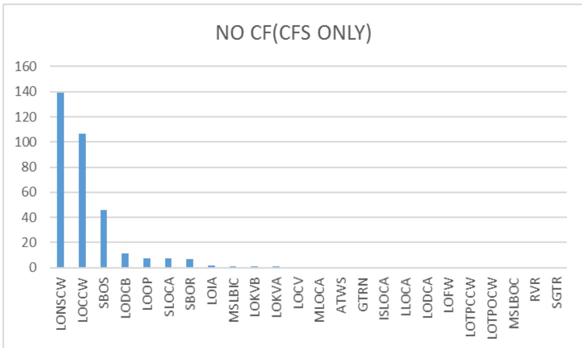

Fig. 5. No containment failure for CFS only

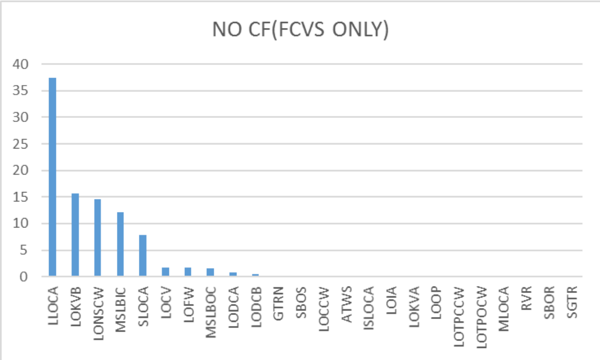

Fig. 6. No containment failure for FCVS only

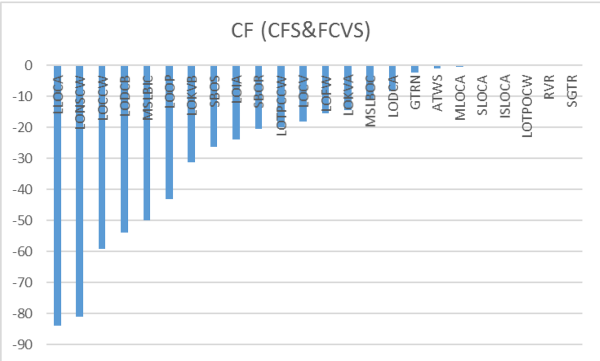

Fig. 7. Containment failure for CFS&FCVS

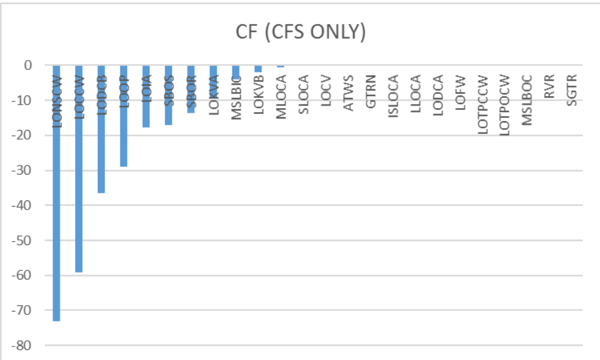

Fig. 8. Containment failure for CFS only

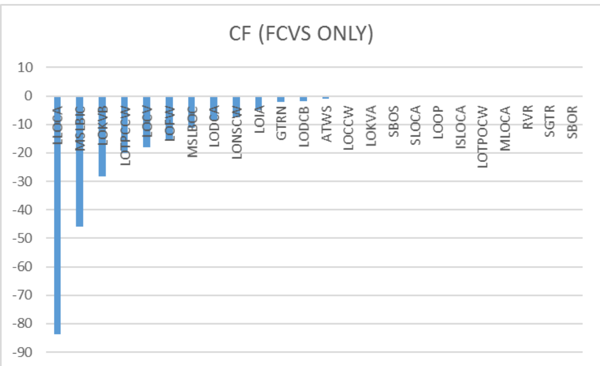

Fig. 9. Containment failure for FCVS only

When the CFS strategy and the FCVS strategy were performed at the same time, the NO CF frequency was increased in the order of Loss Of Nuclear Service Cooling Water System (LONSCW), Loss Of Component Cooling Water (LOCCW) and Station Black Out with EDG failure to start (SBO-S), the same order as the CFS strategy alone. When FCVS strategy alone was performed, the NO CF frequency was increased in the order of Large Loss Of Coolant Accident (LLOCA), Loss Of 4.16kV AC Bus (LOKVB) and LONSCW. And, LLOCA increased more than twice as much as other initial events.

When the CFS strategy and the FCVS strategy were performed at the same time, the containment failure frequency was decreased in the order of LLOCA, LONSCW and LOCCW. When the CFS strategy was performed alone, the containment failure frequency was decreased in the order of LONSCW, LOCCW and Loss Of vital 1.25V DC B (LODCB). When the FCVS strategy was performed alone, the containment failure frequency was decreased in the order of LLOCA, Main Steam Line Break Inside Containment (MSLBIC) and LOKVB.

3. Conclusions

In this study, as a part of the evaluation of SAMSs, we performed level 2 PRA for the reference nuclear power plant whether SAMSs are implemented or not. The CFS and FCVS strategies were selected for the SAMSs, and NO CF and CF frequencies for the initiating events were presented. To reduce uncertainties of it, it is very necessary to further analyze the thermohydraulic analysis of the DET probabilities and the logic of it.

This study can contribute to the basic technology which is necessary for analyzing the impact of SAMSs on an integrity of containment.

Acknowledgements

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