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An Assessment of Fission Product Release Mitigation by CFVS at ECF using MELCOR 2.2

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1. Introduction

There are various containment failure modes in a nuclear power plant, such as Early Containment Failure (ECF), Late Containment Failure (LCF), Basement Melt Through (BMT), etc. The frequency of ECF is low, but early release of fission products is expected when they are generated from the core. So, not enough time is available to take appropriate actions like evacuation or sheltering.

The fission product release after containment failure can be controlled by the Containment Spray System (CSS) and Containment Fan Cooler System (CFCS) [1]. Additionally, Containment Filtered Venting System (CFVS) could be considered in another method at ECF. The CFVS was installed at Wolsong Unit 1, following the post Fukushima action. Also, CFVS is planned to be set up in all units at Kori site [2].

In this study, CFVS performance on fission product release reduction at ECF was evaluated.

2. Methods

CFVS prevents a containment failure by decompressing containment pressure. However, CFVS might not work at ECF because ECF will occur by rapid pressure rise because of Direct Containment Heating (DCH), hydrogen explosion, and steam explosion. In this case, timing to open the CFVS valve might be missed.

Although the containment is already damaged, it is possible to reduce amount of fission product release by using CFVS. If the fission products are released through not the damaged point but CFVS by opening the valve that is in flow path between containment and CFVS, the fission product will be filtered in CFVS and the release amount will be decrease.

2.1 MELCOR Modeling

In this study, MELCOR 2.2 that is a computer code for analyzing a severe accident was used. OPR1000 was selected as a reference plant.

In this OPR1000 MELCOR model, Safety Depressurization System (SDS) and Pressurizer Safety Valve (PSV) was included as systems for decompressing a primary system. Also, High Pressure Safety Injection (HPSI), Low Pressure Safety Injection (LPSI), and Safety Injection Tank (SIT) were considered for the safety injection systems. For secondary system's decompression and feed water supply, Main Steam Safety Valve (MSSV), Atmospheric Dump Valve (ADV), and Auxiliary Feedwater System (AFWS) was also included. Lastly, there were Containment Spray System (CSS) and Passive Autocatalytic Recombiner (PAR) in this model.

The containment was divided into four parts, Dome (CV840), Annular Compartment (CV830), Inner Compartment (CV820), and Cavity (CV810).

The ECF mode was assumed to be classified into leakage and rupture. In case of leakage, the area of flow path was assumed to be 0.0093 m² (0.1 ft²). And the location of flow path was assumed to be at the bottom of the hatch. In the rupture case, it was assumed that a fracture of 0.093 m² (1 ft²) occurred at the dome. And the containment failure was assumed to occur just after reactor vessel breached.

CFVS model was made by referring to AREVA's CFVS that was installed in Wolsong Unit 1 [3]. CFVS tank had 6.5 m height and 3.0 m diameter. Water level was 3.0 m form the bottom and an elevation of sparger was 1.0 m. SPARC model was used for modeling the sparger that is an apparatus for dispersing gas in liquid. SPARC model deals with a phenomenon that occurs between a flow of atmospheric material enters a control volume below the surface of the pool in that volume and passes through the pool to reach its final destination [4]. And this CFVS model did not include any filters.

A diameter of flow path (FL860) that was between containment and CFVS was assumed to be 20 cm, referring to a previous study [5]. A valve in FL860 was assumed not to be a rupture disc but to be a manual valve that is opened manually by an operator. It was a method used in Wolsong Unit 1.

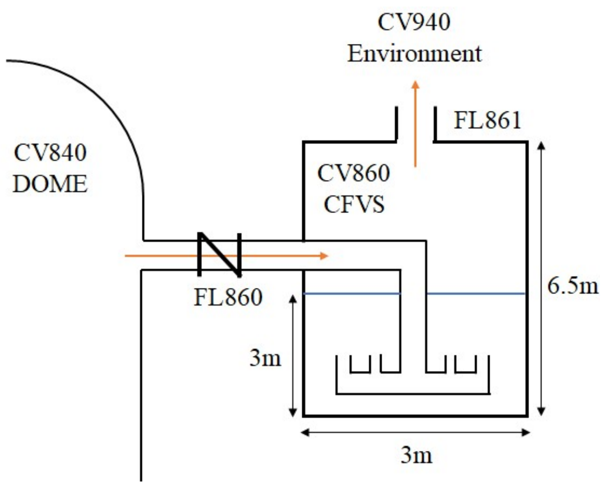

Fig. 1. CFVS model in MELCOR

2.2 Accident Scenario

In this study, the effect of CFVS was evaluated in two scenarios by selecting one by one accident scenarios where leakage or rupture could occur.

According to Multi-Unit Risk Research Group (MURRG)'s previous study, GTRN-84 had a high frequency among accidents that leakage could occur at ECF, and the rate of accidents is fast. Therefore, this accident scenario was selected as representative accident of ECF Leakage. And containment failure scenario followed CET-41. In the scenario, reactor was tripped, and heat removal using primary system and secondary system failed. And both CSS and PAR also failed. Therefore, core was damaged and reactor vessel was breached. A large amount of corium was ejected out of cavity and the DCH occurred. The pressure of containment increased by DCH and the containment was leaked early by overpressure. The containment assumed to be leaked when the reactor vessel breached.

At ECF rupture, GTRN-20, which had the highest frequency, was selected as the representative accident. And containment failure scenario followed CET-41. The reactor was tripped, and early heat removal using secondary system succeeded. However, maintaining heat removal failed and bleed also failed. Although HPSI, CSS, and PAR succeeded, core was damaged because the pressure of primary loop could not be controlled. And then, reactor vessel was breached and a large amount of corium was ejected out of cavity. The DCH occurred and the containment was ruptured early. The containment assumed to be ruptured when the reactor vessel breached.

The details of the accident of GTRN-84 and GTRN-20 could be confirmed in Fig. 2 and the Containment Event Tree of OPR1000 was shown in Fig. 3.

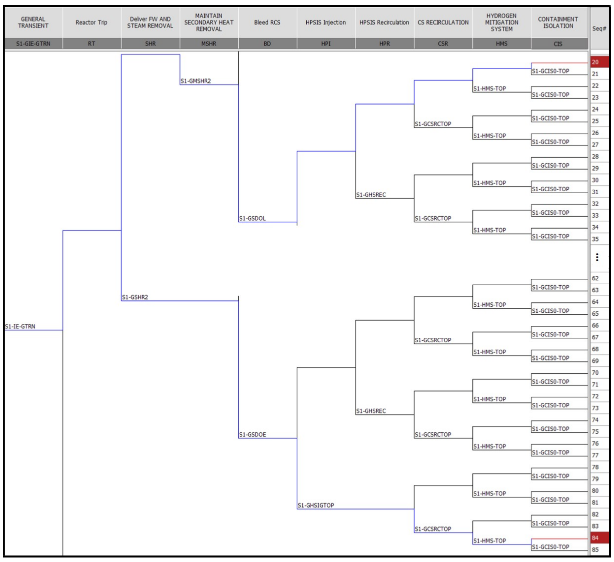

Fig. 2. GTRN Event Tree of OPR1000

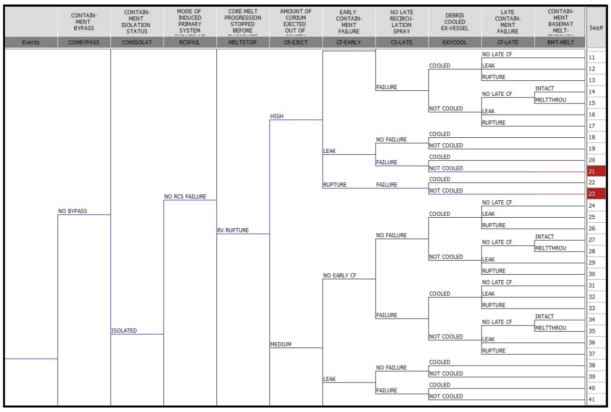

Fig. 3. Containment Event Tree(CET) of OPR1000

The CFVS performance on fission product release reduction is affected by Decontamination Factors(DF) of the filter and the performance of the sparger. However, in this study, filters were not considered and sparger was modeled with same design data in each case. Only the effect of valve open time was focused.

In order to investigate the effect of CFVS valve open time after containment failure on the reduction ratio of fission product release, the valve open time was changed in the cases.

In the leakage case, the valve was opened 0, 1, 2, 3, 4, 5, 6 hours after the containment is damaged. And in the rupture case, the valve was opened 0, 0.5, 1.0, 1.5, 2.0 hours after.

3. Results

3.1 Reduction Ratio of Fission Product Release at Leakage

The reduction rate of each nuclear species release rate according to the valve open time is shown in Fig. 4. Opening the CFVS valve could reduce amount of fission product release, and the faster the valve is opened, the greater the reduction rate. However, amount of Xe class release was not affected by CFVS or slightly increased. This was because the CFVS model used in this study did not include the filter. Therefore, it filtered the fission products using only the sparger. Except Xe class, other nuclides tend to decrease significantly. However, if the valve was opened 1 hour after the containment failure, the reduction ratio was drastically lowered.

In Fig. 5, the reason why fission product release was reduced is shown. The black line of Fig. 5 is the mass flow rate through the damaged area in a case without CFVS. The blue one is the mass flow rate through the damaged area in a case with CFVS. The blue dash line is mass flow rate through CFVS in the second case. If the CFVS valve is opened, the mass flow rate through the damaged area is decreased. It is because some of atmospheric materials are released through the CFVS and filtered.

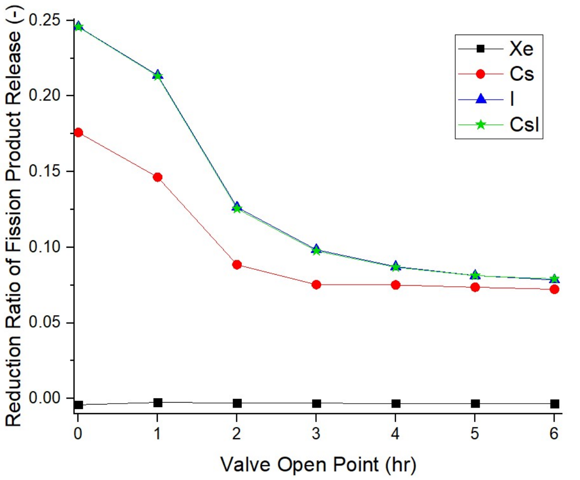

Fig. 4. Reduction Ratio of Fission Product Release according to CFVS Valve Opening Time at ECF Leakage

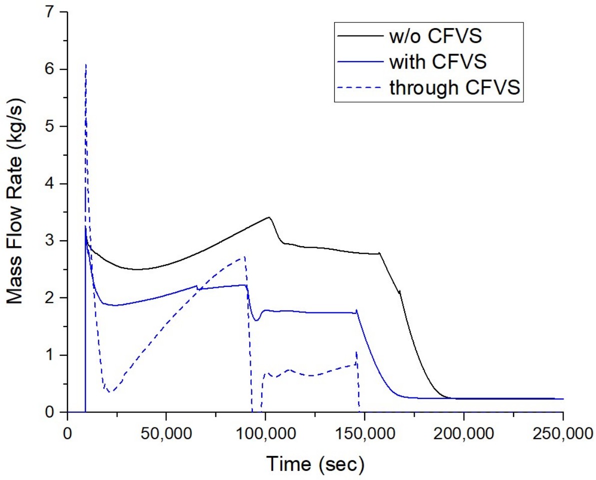

Fig. 5. Mass Flow Rate Change through Damaged Area with and without CFVS

3.2 Reduction Ratio of Fission Product Release at Rupture

The reduction ratio at rupture scenario was shown in Fig. 6. CFVS had little or no effect on the fission product release mitigation at the rupture scenario. In some cases, fission product release is increased.

The reason could be found in Fig. 7. A rapid decrease in containment pressure was caused because of the large area of containment failure at rupture. It could be seen that the containment pressure peaked just before the containment failure and dropped to atmospheric pressure in 40 minutes. The blue line in Fig. 7 represents the flow rate of the atmospheric material through the CFVS. The fission products were released through the CFVS only for about 12 minutes immediately after the containment was destroyed. This means that all of the atmospheric material escaped to the damaged area rather than through CFVS, because the pressure in the containment was rapidly reduced. Therefore, at rupture, the amount of fission product release was not substantially decreased by CFVS.

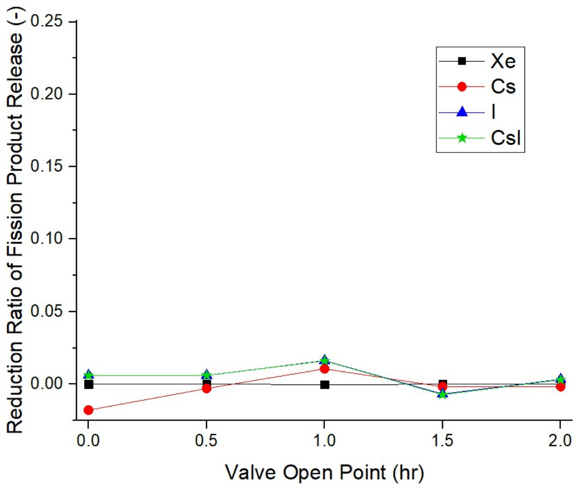

Fig. 6. Reduction Ratio of Fission Product Release according to CFVS Valve Opening Time at ECF Rupture

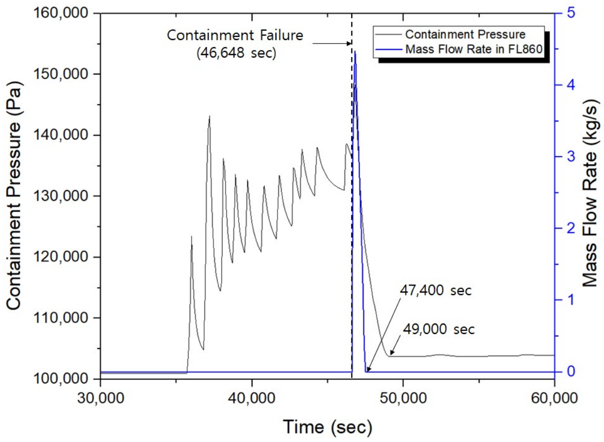

Fig. 7. Behavior of Containment Pressure and Mass Flow Rate in FL860 in OPR1000 ECF Rupture Accident

4. Conclusions

In this study, mitigation of fission product release by CFVS at ECF accidents was assessed. As a result, the amount of fission product release decreased at the leakage, but the efficiency dramatically reduced when the valve was opened 1 hour after the containment failure. In the rupture case, the fission product release showed little or no change.

Therefore, when the containment is damaged early, the containment pressure should be monitored for 1 hour after the containment failure. And if the pressure drops slowly, the CFVS valve should be opened to control the fission product release.

However, this study has limitations in that it is based on previous researches rather than actual design data. Once the CFVS is actually installed in the Kori Site, it is necessary to make accurate analysis with actual design data. Also, additional study on the hydrogen distribution change in containment and CFVS tanks caused by CFVS operation is also needed.

Acknowledgements

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