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The Effect of Water Injection on the Fission Product Aerosol Behavior in Fukushima Unit 1

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1. Introduction

Probability of severe accident in nuclear power plant is not high, however nuclear safety researchers have to prepare for the worst situation because it is directly related with the lives of human. From the Fukushima accident, the importance of preparing about the severe accident could be found. The most important factor affects human health is fission product that is released from the plant.

Fission products usually released with types of aerosol and vapor. The amount of released aerosols out of the plant is crucial, because it can be breathed by people.

In this study, the best estimated scenario of Fukushima unit 1 accident was modeled with MELCOR. The amount of released fission product aerosols was estimated according to the amount of added water into reactor pressure vessel (RPV).

2. Basic model

Basic scenario of Fukushima Unit 1 accident was also studied, and modeling of the plant was also conducted [1]. The nodalization of RPV and primary containment vessel (PCV) were shown in Fig. 1.

2.1 Nodalization and operating conditions

As shown in Fig. 1, the RPV consists of 6 regions, and each volume was connected by using flow path. The PCV consists of 2 regions, pedestal and drywell. Vent leg and wetwell were also simulated. The core and lower plenum were divided into 4 rings and 16 axial nodes, which contain 10 axial levels for the active fuel region.

The operating condition data of Fukushima unit 1 were obtained from tokyo electric power company (TEPCO) through the OECD/NEA BSAF project. SRV operation, alternative water injection, isolation condenser and suppression chamber vent were considered. In addition, leak from SRV gasket, instrument pipe, main steam line and PCV head flange were also reflected [1].

2.2 Aerosol dynamic model

In order to account for the aerosol behavior, some conditions were assumed. Sectional method was used in MELCOR. 10 sections were considered and hygroscopic model was used to simulate aerosol condensation and evaporation. The amount of radionuclides in fuel gap was determined by considering reference [2], and the gap release temperature was set to 1173 K. CORSOR-BOOTH model was employed to simulate the release of fission products in molten fuel. The minimum and maximum diameters of aerosol were fixed to 0.1 and 500 micrometer, respectively. 2 components were employed, water and the others. The effect of pool scrubbing in wetwell through SRV was considered [3].

As the representative fission products, cesium hydroxide (CsOH) was observed in this study.

2.3 Justification of basic model

In order to conduct sensitivity study using this model, it is necessary to compare the results with measured data. In the case of Fukushima Unit 1, there were few data, such as water level and pressure in RPV. As shown in previous study, the calculation results were well followed the measured data [1].

2.4 Alternative water injection

Water injection into RPV was conducted in order to remove the decay heat. However, the exact quantity of water reached to the RPV was not clear due to the

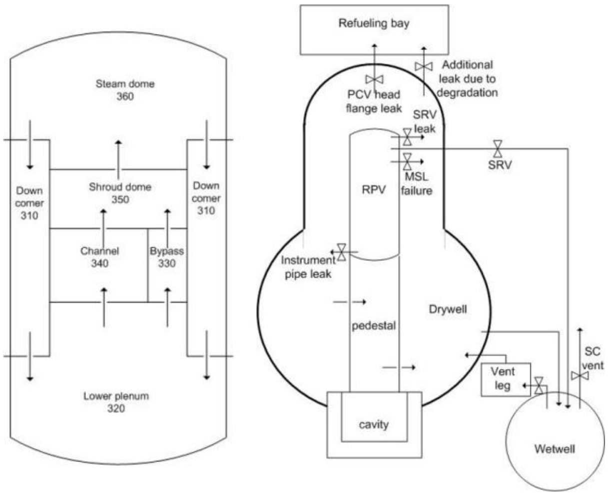

Fig. 1 Nodalization of RPV and PCV

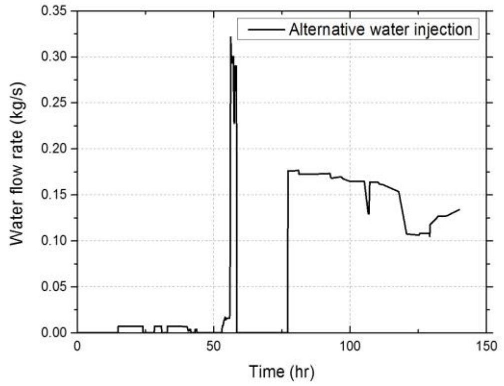

Fig. 2 Alternative water injection flow rate

damages in the flow pipe. Thus the fission products concentrations outside of the PCV were observed with changing the water flow rate. Basic water flow rate is indicated in Fig. 2.

3. Result and Discussion

3.1 General accident scenario

Station black out (SBO) accident occurred after arriving of tsunami. At the initial stage of accident, operation of isolation condenser reduces the pressure of RPV, but it does not last for long. Phase change of coolant in the vessel made large amount of steam, and the steam escapes into the wetwell through the safety valve. As the fuel rod exposed to steam, fuel gap released at 4.7 h. Main steam line failure occurred at 6.8 h and it caused the pressure drop in the. At 9.2 h, water dryout in reactor vessel was observed, and debris ejection to cavity was found at 9.9 h [1].

3.2 Aerosol formation

Fission products were released from fuel as a vapor, and aerosol could be formed according to the temperature and pressure conditions. The vapor

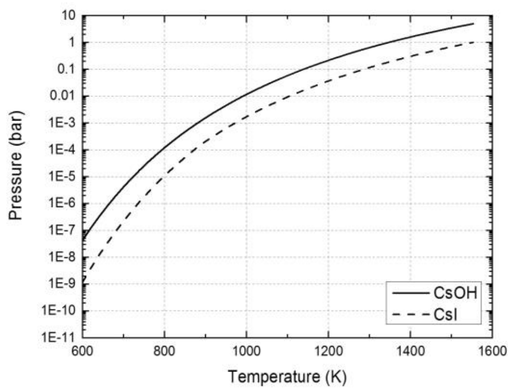

Fig. 3 Vapor pressure of CsOH

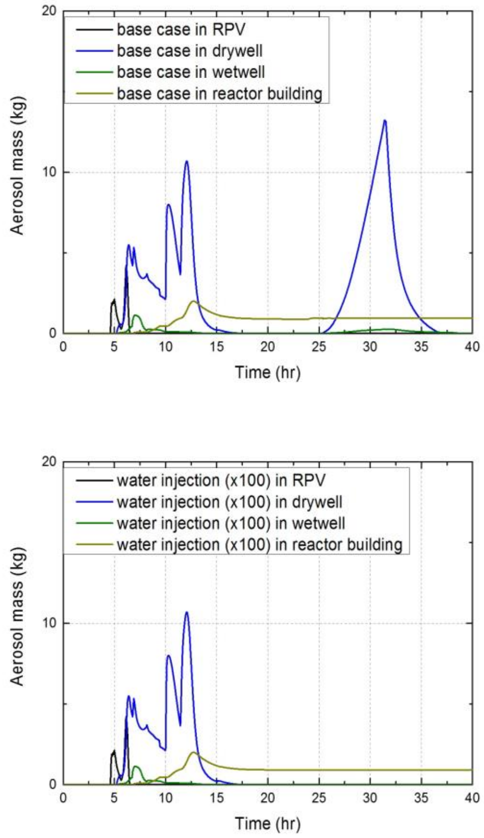

Fig. 4 Fission product behavior (a) base case (b) 100 times water injection case

pressure of CsOH was shown in Fig. 3. When the vapor pressure exceeds the vapor curve, aerosol was formed as the excess amount. When cold water was supplied into the RPV, the temperature in PCV decreased. Aerosol could be formed as the pressure increased at a constant temperature as shown in Fig. 3. The generated aerosols were inserted into the smallest section [3].

3.3 Fission products behavior at initial stage of accident

Comparison result of fission products behavior was shown in Fig. 4. In this graph, only aerosol mass in the atmosphere was presented, and it was observed in RPV, drywell, wetwell, outside of PCV. The result of base case was shown in Fig. 4(a), and the Fig. 4(b) contains the result of increasing water case. The fission product behavior was the same before injecting water into the RPV. The fission product stored in the fuel gap was released to the pressure vessel at 4.7 h, so peak of mass was observed. The CsOH were transferred to drywell due to the instrument pipe leakage at 5.3 h and the SRV gasket leakage at 5.2 h, so it was shown that the fission product mass in RPV is decreased. As the temperature of fuel increased, large amount of fission products were released from molten fuel at about 6 h. At 6.8 h, main

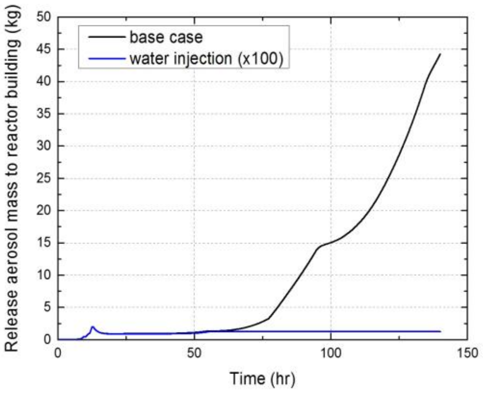

Fig. 5 Aerosol mass in reactor building

steam line failure occurred, almost fission products were

transferred to drywell. The suspended aerosols mass in the atmosphere decreased through the deposition, settling and fallout. Furthermore, the leak from PCV head flange made the aerosol into the outside of PCV, which is reactor building. At about 10 h, molten core materials were ejected into the cavity through the rupture part of lower head. The corium concrete reaction made large amount of fission products so the peak of aerosol in drywell was found. The generated fission products were also moved into wetwell through the SRV and ventleg. All water in cavity were evaporated at 12 h, another aerosol mass peak was detected. The PCV head flange leakage path was opened from 10 h, so some portion of the fission products were also released to the reactor building.

Difference between Fig. 4(a) and (b) is the peak at about 30 h. After 15 h, large amount of aerosols were deposited on cavity floor. In the case of Fig. 4(a), temperature of the deposition surface was increased continuously so some aerosols were suspended again. Although water injection was performed, the water flow rate was not high enough to cool down the surface. After increasing the flow rate to one hundred times, the surface temperature was decreased, so there was no aerosol re-suspension.

3.4 Release of fission products to reactor building

The amount of released fission product into the environment is the most important point in the nuclear plant accident. As shown in Fig. 5, the released aerosol mass in base case is about 35 times larger than the other case. In the base case, the injected water was not enough to remove the decay heat. As the temperature of deposition wall is high, the possibility of aerosol suspension increased. The aerosol masses in deposition surface were indicated in Figs. 6. Large amount of aerosols were remained in pedestal and drywell floor in the case of 100 times water injection.

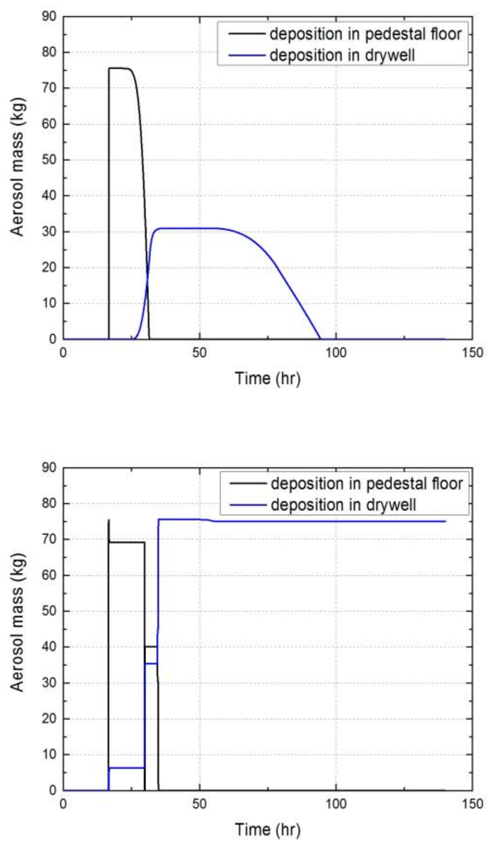

Fig. 6 Aerosol mass in deposition area in PCV (a) base case (b) 100 times water injection case

4. Conclusions

The analysis of Fukushima unit 1 accident was conducted in view of fission product aerosol release using MELCOR. First of all, thermodynamic results of the plant were compared to the measured data, and then fission product aerosol (CsOH) behavior was calculated with changing the amount of water injection. Water injection affects the amount of aerosol which released into reactor building, because it decreases the temperature of deposition surface. In this study, only aerosol behavior was considered, further study will be conducted including hygroscopic model.

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