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Effect of RCIC Operating Conditions on the Accident Scenario in Fukushima Unit 2

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1. Introduction

Researches on the boiling water reactor (BWR) plant with reactor core isolation cooling (RCIC) system have been conducted [1,2]. Research on the RCIC operation in Fukushima unit 2 was also conducted by Sandia National Laboratory [3]. MELCOR analysis of the Fukushima unit 2 accident was conducted in the report and energy balance in wetwell was described by considering RCIC operation. However, the effect of RCIC operation condition on the accident scenario has not been studied. The operating conditions of RCIC system affect the pressures in wetwell and drywell, and the high pressure can make leakage path of fission product from PCV to reactor building. Thus it can be directly related with the amount of fission product which released to environment.

In this study, severe accident on Fukushima unit 2 was analyzed considering the operating condition of RCIC system, and best estimated scenario was presented. In addition, the effect of RCIC turbine efficiency on the accident progression was examined. Energy balance in suppression chamber was also considered with discussion on the effect of torus room flooding level. Finally, the effect of RCIC turbine efficiency on fission product release was found in this study.

This study was conducted by using MELCOR 1.8.6 [4,5].

2. Model

In order to analyze the accident scenario, it is important to model the Fukushima unit 2 plant accurately. The model consists of reactor pressure vessel (RPV), primary containment vessel (PCV), reactor building (RB), core part and several safety features. Normal operating conditions and boundary conditions were obtained from TEPCO [6].

2.1 Plant

Nodalization of RPV and PCV is indicated in Fig. 1. As shown in Fig. 1, the RPV consists of downcomer, lower plenum, core, bypass, shroud dome, separator, steam dryer and steam dome. Jet pump was included in downcomer and recirculation pump between downcomer and jet pump was also modeled. The flow paths inside the RPV were also indicated. Several control valves were employed to simulate water injection into the downcomer during RCIC operation and alternative water injection period. In Fig. 1, nodalizations of drywell and wetwell are shown. The drywell consists of four parts, pedestal region and other drywell regions. There is a flow path between wetwell and vent leg, and vacuum breaker is located in the flow path. Sea water was injected into torus room at the tsunami arrival time to simulate torus room flooding and it was controlled by operation of control valve with time. RCIC system operation was included in the analysis, and the source of injection water was condensate storage tank and suppression pool. Safety relief valve (SRV) operation and alternative water injection to core were considered. Leakages from PCV were also considered, and the operating principle of the leakages was explained in the next section. Reactor buildings which contain torus room, refueling bay and turbine building were included in the analysis, and Peach Bottom data was referred to obtain the geometrical information. [7] A volume was assigned to environment.

2.2 Torus room flooding

In case of Fukushima unit 2, it is estimated that the torus room was flooded when plant was hit by tsunami. Although the amount of water flew into the torus room is not known, it is expected that some portion of heat energy in the suppression pool was transferred to sea water in torus room. The heat transfer would take place as conduction through torus wall, the material of wall is stainless steel. The heat structures consist of 1 horizontal wall at bottom and 10 vertical walls and several heat structures were employed to model the heat conduction exactly. Heat transfer area between torus and sea water in torus room is changed with the flooding level. After arriving of tsunami, it was assumed that the flooding level was increased slightly with time. The heat transfer area was also increased with increasing the water level.

2.3 RCIC system

The RCIC system is designed to conduct proper cooling of core by providing sufficient water into the RPV with high pressure steam in steam dome. It is expected that the RCIC system in the case of Fukushima unit 2

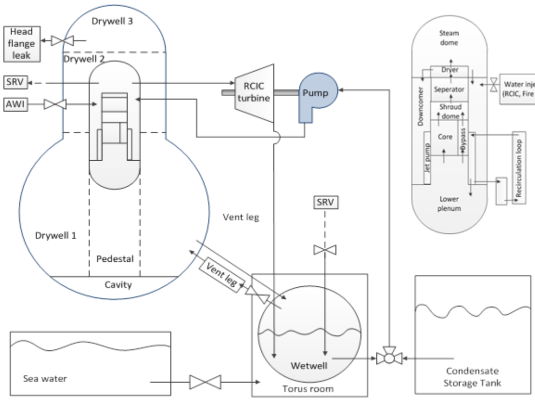

Figure 1 Nodalization of RPV and PCV

accident is not operated in normal conditions. This is because that the inlet condition of RCIC turbine was mixture with steam and water, and the turbine behavior in mixture inlet condition is not known exactly. The schematics of RCIC operation condition is indicated in Fig. 2. As shown in Fig. 2, not only steam but also the water above the main steam pipe would be transferred to RCIC system. Thus it was assumed in this study that total amount of water above the pipe should be transferred to RCIC turbine in the analysis. In addition, the steam extraction rate was determined by comparing the RPV pressure with measured data. The inlet mixture of RCIC turbine has high enthalpy with high pressure and temperature, and the enthalpy should be decreased after passing the RCIC turbine. The energy would be used to operate the RCIC turbine. However, the enthalpy change of the process is unknown accurately,

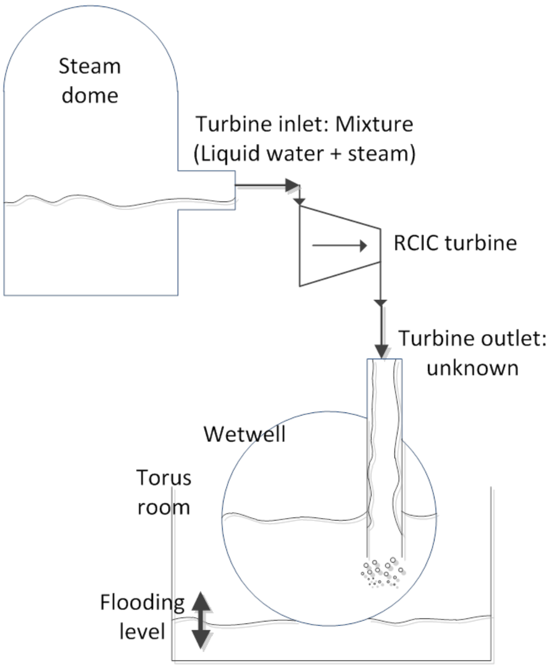

Figure 2 Schematics of RCIC turbine operating condition.

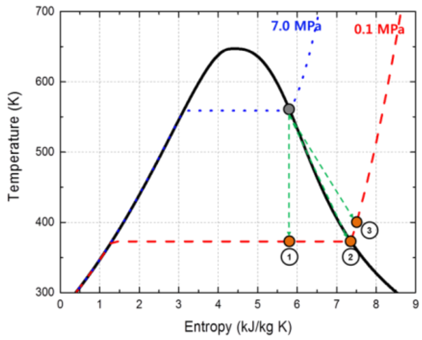

Figure 3 Temperature-entropy diagram in RCIC turbine processes.

because the operating condition of RCIC turbine in mixture inlet condition is also uncertain. Thus possible turbine process paths were discussed as shown in Fig. 3, and best estimate case was determined.

3. Results

The operation of the RCIC system was one of the important factors to reduce the damage of the core in unit 2. It was found that the core in reactor vessel was cooled down properly by supplying low temperature water from CST or wetwell into the RPV during operation of RCIC system, and the core degradation occurred after the RCIC system stopped. Although the operating conditions of RCIC system did not affect the degree of core degradation directly, the conditions can be important to analyze the accident scenario.

In case 1, it was assumed that the turbine work is maximized without the increment of entropy. It means that the transferred energy from RCIC turbine to wetwell will be minimized. However, it is general that turbine efficiency is smaller than the isentropic case in real situation, thus the efficiency of turbine was considered in the case 2. There have been many attempts to simulate the RCIC turbine with applying different turbine efficiencies, and the saturation steam

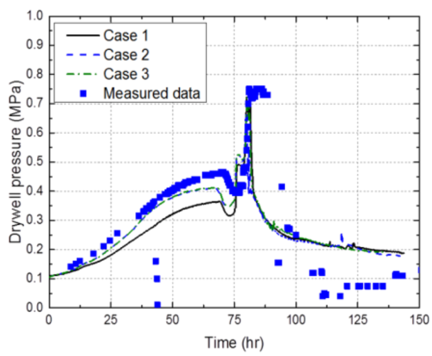

Figure 4 Drywell pressure of each case.

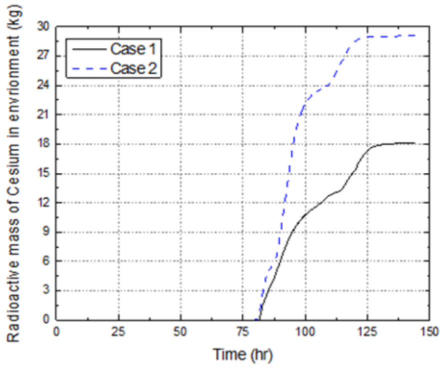

Figure 5 Radioactive mass of cesium in environment.

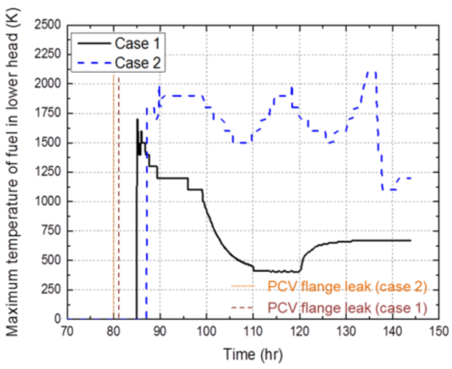

Figure 6 Maximum temperature of fuel in lower head.

condition at the turbine outlet was selected as case 2. Definition of isentropic efficiency of turbine is the ratio of the actual work output to the work output if the turbine undergoes an isentropic process. Turbine isentropic efficiency is about 0.15 in the case 2. Finally, the degree of superheat in the turbine outlet steam was considered, and the turbine efficiency is about 0.1 in case 3. The measured drywell pressure data was compared with calculation values in Fig. 4. It was found that the drywell pressure in the isentropic case is lower than measured data. It means that more energy should be transferred to suppression pool and RCIC turbine efficiency should be decreased. In the case 2, the calculation result was closed to measured data. A portion of energy was used to operate the RCIC turbine, and the rest energy contributed to increase the pressure and temperature of suppression pool. In this case, the turbine efficiency is smaller than normal operating condition. This is because that the liquid water in mixture had a negative effect on the turbine operation. In the case 3, the trend of drywell pressure is similar to the saturation steam case. This is because the amount of transferred energy to wetwell was not changed largely. PCV head flange leakage model was employed in this study, and the criterion of the leak is drywell pressure. Thus the operating condition of RCIC turbine can affect not only the PCV pressure but also the amount of released fission products. The total amount of released fission products to environment was investigated, and the amount of cesium (Cs) as representative radionuclide was indicated in Fig. 5. As shown in Fig. 5, it was indicated that the total amount of released cesium was increased as the transferred energy from RCIC turbine to wetwell was increased. It was also found that the difference was originated from the degree of core degradation due to the difference of the amount of water in the RPV. In Fig. 6, the comparison graph of maximum fuel temperature in lower plenum was shown. Although the fuel relocation time to lower plenum in case 2 was later than case 1, the higher temperatures were maintained continuously. It means that the fission product release rate in case 2 is higher than case 1. Therefore, the RCIC turbine operating condition can affect the degrees of core degradation and the amount of released fission products.

4. Conclusion

Fukushima unit 2 accident was analyzed using MELCOR in this study, and best estimate scenario with considering RCIC operating conditions was presented. Three cases of RCIC turbine operation condition were assumed and the most acceptable condition was explained. It was found that the operating condition of RCIC turbine not only affects the variation of drywell pressure but also the amount of released fission products to environment. It was also confirmed that the RCIC turbine efficiency in the accident would be less than normal operating condition.

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