Studies on the Effect of Steam Generator Geometry on C-SGTR accident

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1. Introduction

Steam generator tube rupture (SGTR) accident is one of the most important accident scenarios should be considered to ensure regulations on the severe accident in Korea. Though the probability of spontaneous SGTR accident that is progressed to severe accident is not high, consequential SGTR (C-SGTR) accident is more probable [1]. C-SGTR is potentially risk significant events because thermally induced SG tube failures caused by hot gases from a damaged reactor core can result in containment bypass event and a large release of fission products to the environment [2]. Some studies already found that combustion engineering (CE) plants have more probability of C-SGTR than westinghouse (WH) plants, because of the differences of reactor coolant system (RCS) and SG geometries [2]. The geometries could be slightly different in the CE type plants, so it is necessary to study on the effect of steam generator geometry on SGTR accident in domestic operating power plants. This is because that it could affect not only the accident scenario but also the amount of released fission products to environment.

In the study, the accident progression and the amount of released fission products during C-SGTR accident were analyzed with the geometries of steam generator using MELCOR 2.2.9607. MELCOR input was revised to simulate different mixing ratio in steam generator inlet plenum and in hot tube fractions in SG tube. The mixing ratio and hot tube fraction are one of the most important factors to determine the SGTR occurrence time. In addition, several models in the MELCOR input such as natural leak of containment, Main steam safety valve (MSSV) and atmospheric dump valve (ADV) operation conditions were improved with comparing previous study [1].

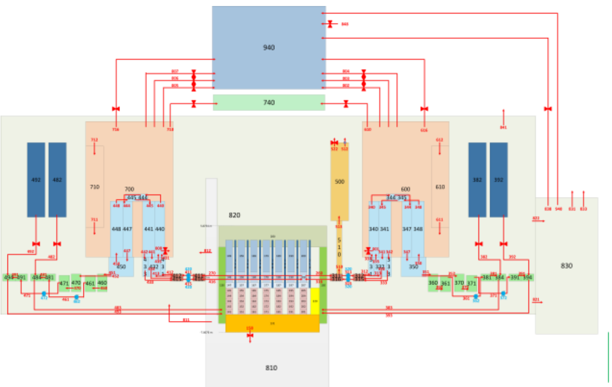

Fig. 1. Nodalization of OPR1000 plant for MELCOR calculation

2. MELCOR input

2.1.Plant nodalization

Target plant is OPR1000 nuclear power plant, and it was divided into several nodes to conduct MELCOR calculation. The nodalization of the plant is indicated in Fig. 1. Basic concept of the nodalization is similar to the previous study except for some revisions [3]. Hot legs were divided vertically into two nodes to simulate natural circulation in RCS. Moreover, the SG inlet plenums were divided into three nodes representing for hot gas, mixing gas, and cold gas region. SG tubes were also divided into two nodes to simulate hot region and cold region. Four cold legs were modeled. MSSV is also modeled to consider the real operating plant setting pressure values. In addition, ADV open is modeled after 30 min. of 923 K of core exit temperature (CET). Natural leak of the containment was assumed.

2.2.SG geometry model

Recommendation of mixing fraction and flow parameters were presented from previous study [2] and it was found that 0.65 of mixing fraction and 22% of hot tube fraction in the case of CE plant. However, the values could be varied in the same CE type plant. Therefore, MELCOR calculation was conducted with

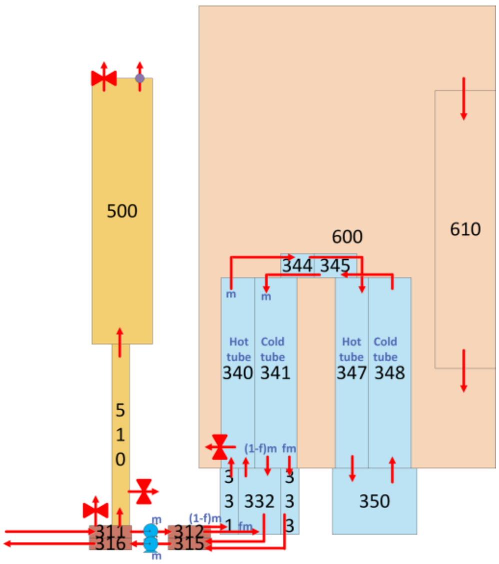

Fig. 2. Mixing fraction and hot tube fraction in steam generator

Table 1 Summary of accident scenario

Event	Time (s)
Reactor trip (SBO)	0
MSIV close	0
SG secondary dryout	6,000
First operation of SRV(of PRZ)	7,600
CET is 923 K (ADV open)	12,250
Fuel gap release	14,000
SGTR occurrence	18,300
Lower head penetration failure Debris ejection to cavity	21,900
SIT injection start	22,000
End of calculation	30,000

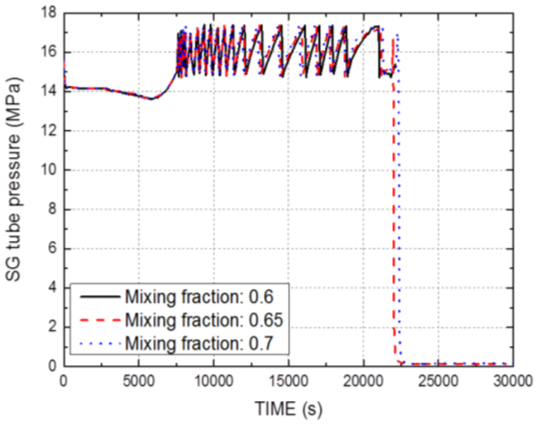

Fig. 3. SG tube pressure with different mixing fraction

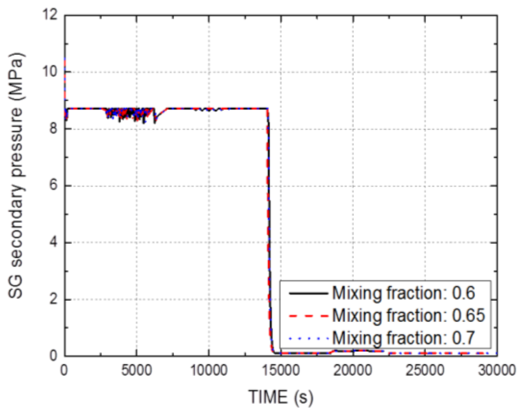

Fig. 4. SG secondary pressure with different mixing fraction

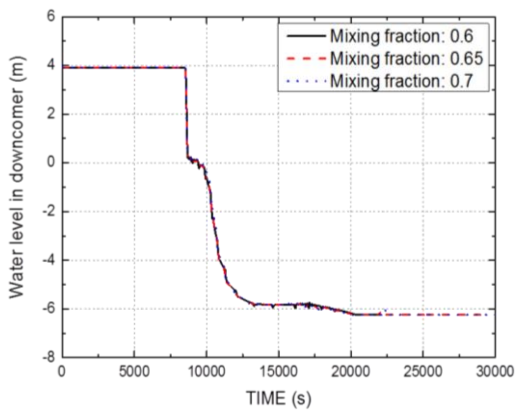

Fig. 5. Water level in downcomer of RPV

changing node properties of the SG inlet plenum and SG tube. It would be possible that the mixing ration affects to the hot tube fraction, however, separate effect of each variable was observed in this study. The definition of mixing fraction and hot tube fraction are shown in Fig. 2.

2.3.Accident scenario

Accident scenario of base case (mixing fraction: 0.65, hot tube fraction 0.22 which are recommended values for CE type plant in NUREG-2195) considered in the calculation is summarized in Table 1. Several sensitivity studies were conducted with changing mixing fraction and hot tube fraction in SG in order to confirm the effects of the factors on accident progression and the amount of FP release. At time of 0 s, reactor trip occurred with station black out (SBO) accident. The core cooling was conducted until the coolant was remained in the SG shell. After dryout of the SG secondary volume at about 6,000 s, water level in the RPV started to decrease with operation of safe relief valve (SRV) in pressurizer at 7,600 s. At 12,250 s, CET temperature reached to 923 K and ADV in one side of SG was assumed to open with operator action. Fuel gap release occurred at 14,000 s, and SGTR was observed at 18,300 s. After that, core support plate structures inside RPV were collapsed, and finally lower head penetration failure was detected at 21,900 s. Safety injection tank (SIT) was initiated right after the vessel failure with pressure decrease, however it did not affect the accident progression. The calculation was finished at 30,000 s.

3. Results

Sensitivity calculations were conducted with changing mixing fraction and hot tube fraction. The recommendation for mixing fraction and hot tube fraction are 0.65 and 22% in previous study, respectively [2]. The effect of the variables on accident scenario and SGTR timing was studied in the calculation. Actually, the variables have a predicted range in the existing study, and the value was chosen by considering the study [2]. The mixing ratio varied from 0.6 to 0.7 and hot tube fraction was changed from 22% to 30%.

The pressures of SG tube are shown in Fig. 3, and the SG shell pressures are also shown in Fig. 4. There was no much difference between general trends of the SG pressure behaviors. As indicated in the Fig. 4, the ADV open time by operator were almost the same. In addition, the tendency of decreasing water level in downcomer of RPV was also similar, as shown in Fig. 5.

In the case of the amount of the FP released to environment, higher release rate was found as smaller mixing fraction. It was related with the fuel temperatures during the accident progression. The one of the fuel temperatures were indicated in Fig. 6, and it

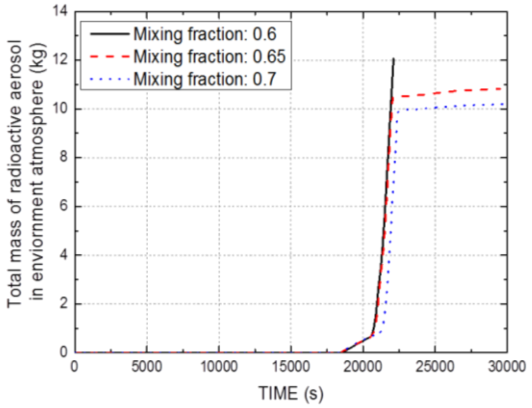

Fig. 6. Total mass of radioactive aerosol in environment with different mixing fraction

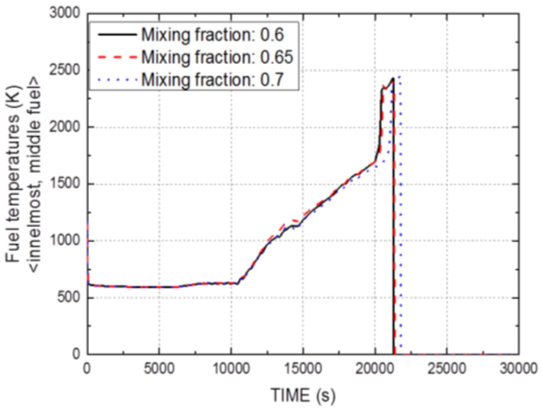

Fig. 7. Fuel temperatures with different mixing fraction

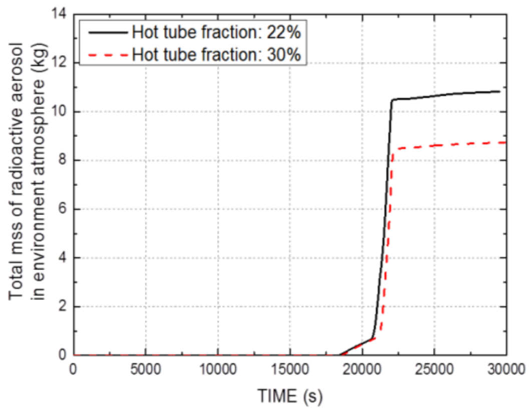

Fig. 8. Total mass of radioactive aerosol in environment with different hot tube fraction

was indicated that fuel temperatures were increased faster as the mixing fraction was smaller. SGTR occurrence timing was not much different between each case. However, more sensitivity calculations would be necessary to determine the effect of the mixing ratio on the amount of FP release fraction into environment.

FP release fraction result with different hot tube fraction is presented in Fig. 7. Smaller hot tube fraction means that higher SG tube temperature and it is related with faster SGTR timing. Accordingly, the total amount of aerosol FP released to environment was increased in case of smaller hot tube fraction.

4. Conclusion

The effect of SG geometries on C-SGTR accident progression was studied. It was expected that the geometries of SG could affect the flow pattern in the RCS loop and it would be related the FP release fraction. From the sensitivity study with changing variables of mixing fraction in SG inlet plenum and SG hot tube fraction, it was found that the hot tube fraction is more sensitive than the mixing fraction. The smaller hot tube fraction caused the faster temperature increase of SG tube and it was connected faster SGTR. In the case of mixing fraction sensitivity study, it is necessary to conduct more sensitivity studies in order to determine the effect of the variable on the accident progression accurately.

ACKNOWLEDGEMENT

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