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Investigation on fission products release mitigated by in-containment relief valve under SGTR accident

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1. Introduction

In Nuclear Power Plants (NPPs), prevention of fission product release is very important to guarantee safety. A containment building is designed as the last barrier to prevent the fission product release under severe accident scenarios. Release of fission product can differ with accident types. In most of the severe accident scenarios, even if a reactor core is damaged severely, the fission products can be retained inside the containment if the containment building is intact. However, in a bypass scenario of Steam Generator Tube Rupture (SGTR), radioactive nuclides are released to environment even if the containment is not ruptured.

The SGTR is considered as a representative accident scenario which leads to bypassing the containment building in Pressurized Water Reactor (PWR). During an extreme situation of station blackout transient, SG U-tube integrity could be threatened by thermally- or pressure-induced creep rupture [1]. If the U-tube is broken by the mechanisms, the reactor pressure boundary may not be retained, and primary coolant can be transferred to the secondary system. Under these sequences, extensive core damage causes release of the radionuclides from the fuel to the coolant. Accordingly, the radioactive nuclides of the secondary system can be released to the environment through Main Steam Safety Valve (MSSV) or Atmospheric Dump Valve (ADV). Therefore, to fortify the safety of the NPP during the SGTR accident, more creative mitigation strategies need to be devised.

In this study, a conceptual approach was taken to mitigate the consequence of SGTR accident by generating additional paths from SG to in-containment space of dome to the RDT. To investigate its effectiveness, MELCOR input model of OPR1000 reactor was used.

2. Numerical methods

2.1 MELCOR input model of OPR1000

The OPR1000 was selected as a reference plant for SGTR analysis using MELCOR code [2]. MELCOR nodalization of the OPR1000 is shown in Fig 1. The input model consists of two SGs, two hot legs, four cold legs, and a pressurizer in Reactor Cooling System (RCS). In addition, Pressurizer Safety Relief Valve (PSRV) and Safety Depressurization System (SDS) are also modelled for depressurization of the primary system. The secondary system includes SG and safety features such as ADV and MSSV. A reactor cavity is modelled to simulate Molten Corium Concrete Interaction (MCCI)

2.2 SGTR accident scenario

The SGTR scenario was selected as the main accident scenario due to the bypassed release of radionuclides to the environment unlike other accident scenarios such as SBLOCA, SBO, and TLOFW [3]. To investigate effectiveness of a new mitigation strategy creating additional pressure relief paths, very conservative conditions with the SGTR scenario were applied in this simulation. First, the accident started with a complete break of one U-tube in SG, with flow area of 4.49×10^{-4} m^2. Second, the active safety systems such as High-Pressure Safety Injection (HPSI), Low Pressure Safety Injection (LPSI), and SDS were assumed to fail. Finally, the auxiliary feed water system (AFWS) was assumed unavailable in the secondary system. Henceforth, only the passive safety features such as PSRV, MSSV, and SITs were assumed available in the simulation.

2.3 In-containment relief valve (ICRV)

This study simulated 3 cases to confirm effectiveness of the additional pressure relief paths. A base case simulates no additional paths. So, the radionuclides contained in steam can be released to the environment directly via the MSSV. However, the other cases simulate In-containment Relief Valve (ICRV) and do not allow release of radionuclide to the environment. Thus, if the SGTR occurs, radionuclides are directed to be discharged into the containment. In the containment (CNMT) case, an additional path (CNMT-DV) was conceptually created between SG and upper dome of the containment. In the RDT case, the other additional path (RDT-DV) was created between SG and RDT. Especially the condensation effect was investigated in the RDT case because relatively small volume of the RDT may not accommodate the substantial amount of steam release from the SG if effective condensation of the steam does not occur. The path parameters such as flow area, length, and open pressure were determined based on the specifications of the MSSV. A schematic of the CNMT and RDT cases is shown in Fig 2.

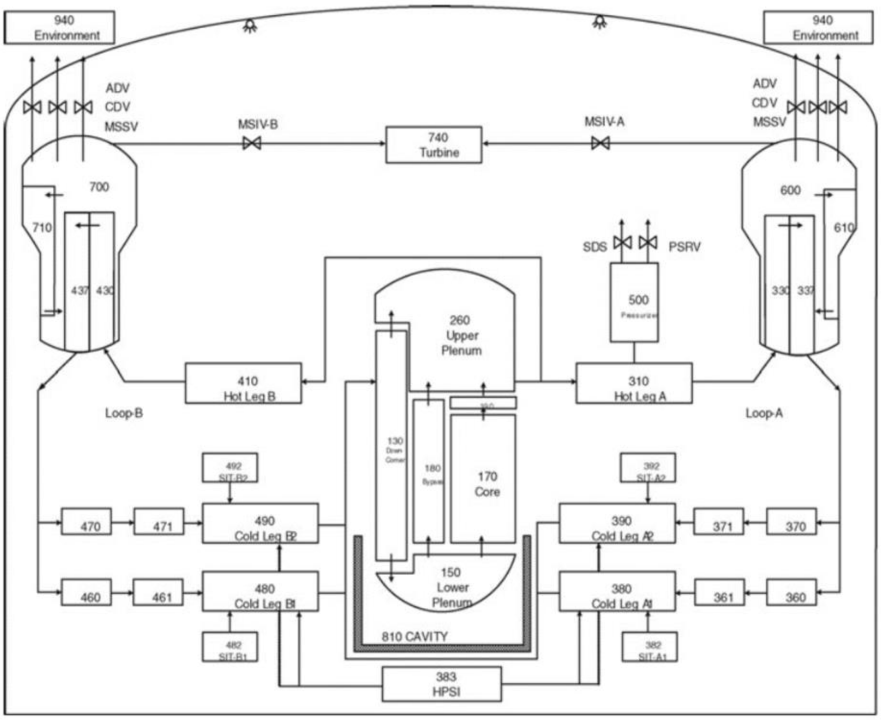

Fig. 1. MELCOR nodalization of OPR1000.

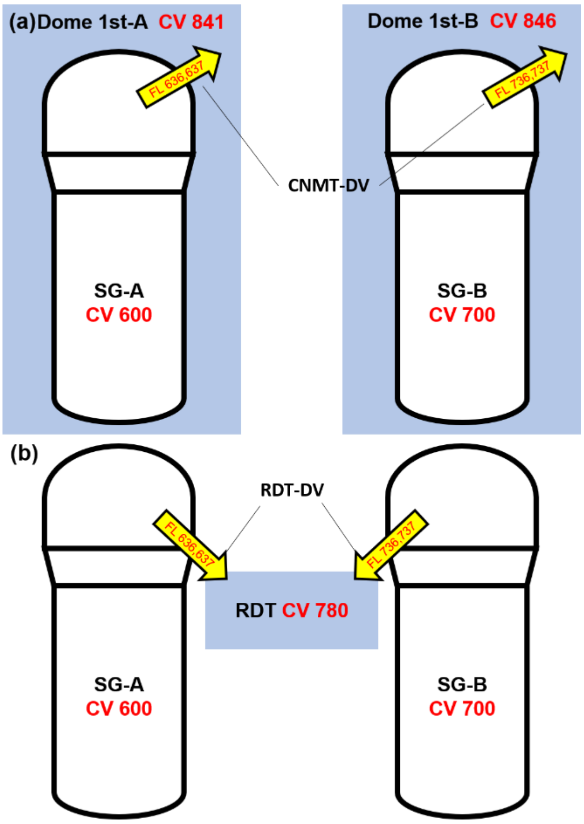

Fig. 2. Schematic of simulation cases (a) CNMT case, (b) RDT case.

3. Results and discussion

After steam generator tube rupture, the coolant of primary system was released to the secondary system. The high pressure of the primary system increased the pressure of the secondary system. It caused the secondary system pressure to reach the MSSV open pressure at the early stage of accident (0.74 h). However, the radionuclides were not released to the environment because it existed only in fuel before the gap release. Because the reactor coolant pump was damaged by cavitation, decay heat was not removed properly. Temperature of the core increased, and gap release occurred. After gap release time, the radionuclides were released to the coolant and were transported to the secondary side. So, it was predicted that the radionuclides could be released to the environment after the gap release. But, the release of the radionuclides stopped at the time of Reactor Pressure Vessel (RPV) failure. It is because the primary and secondary system pressure decreased at the time of RPV failure. So, the MSSV was closed with lower pressure and the radionuclides were not released to the environment after RPV failure. This is clearly seen in Fig 3 (a), in which the release of the radionuclides to the environment was stopped after RPV failure.

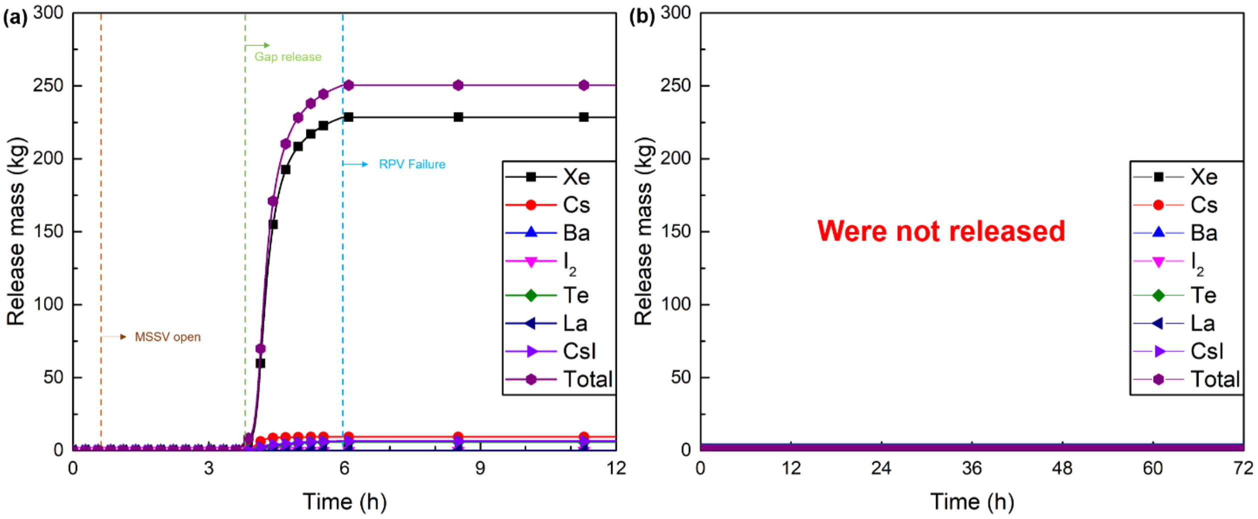

Fig. 3. The release mass of radionuclides to the environment (a) the base case, (b) the CNMT and RDT cases

The CNMT case and RDT case were modelled to compare the release of radionuclides with the base case. In these cases, the radionuclides were not released to the environment because of the created paths connecting the secondary system and containment inner space (ICRV; CNMT-DV, RDT-DV). The radionuclides in the secondary system were released to the inside of the containment building in the CNMT and RDT cases. Fig 3 (b) shows the released mass of the radionuclides to the environment in the CNMT case and the RDT case. In two cases using ICRV, if the containment building is intact, the radionuclides were not released to the environment.

As an adverse effect, however, it was expected that in the CNMT and RDT cases using ICRV might cause the overpressure in the containment. The overpressure can create crack on the containment building and causes release of the radionuclides to the environment. Thus, the containment pressure was calculated and presented in Figure 4. In the CNMT and RDT cases, pressure of the containment increased after the MSSV open. However, the base case pressure didn’t increase by MSSV open because the steam was not released to the inner space of the containment building. After RPV failure, a large amount of steam and corium were ejected to the cavity, so containment pressure was peaked. Then, the containment pressure increased by boiling off the water in the cavity until cavity experienced a dryout. Although the water was completely evaporated, the pressure increased by the MCCI and decay heat of ex-vessel corium. It leads to pressure increase as shown in Figure 4. Consequently, in the CNMT and RDT cases, containment pressure was much higher than that in the base case, and the pressure difference between the base case and the RDT case reached almost 0.48 MPa at 72 hours later since the accident started.

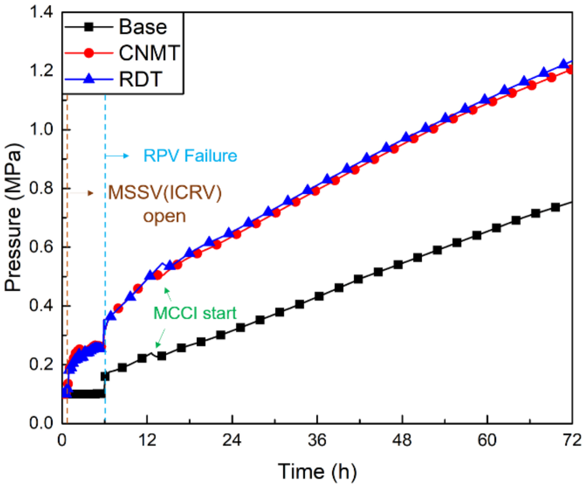

Fig. 4. Comparison of containment pressure (Upper dome)

The RDT case was expected the lower containment pressure than the CNMT case because of the steam condensation by water in the RDT. However, the containment pressure in the RDT case was higher than the CNMT case after RPV failure (Fig 4). This is because the water of RDT is evaporated and affects the containment pressure in the RDT case. In the RDT case, the steam of secondary system released to the RDT. The released high temperature steam through PSRV and ICRV boiled the water of RDT. Additional water (RDT water) released to the containment building. So, depressurization strategy using RDT is not effective for ICRV. And the main factor that increases containment pressure is ex-vessel corium heat. Non-condensable gas generated by MCCI and the decay heat of the ex-vessel corium increased the containment pressure. Therefore, the ex-vessel corium needs to be cooled for effective usage of the ICRV without adverse results.

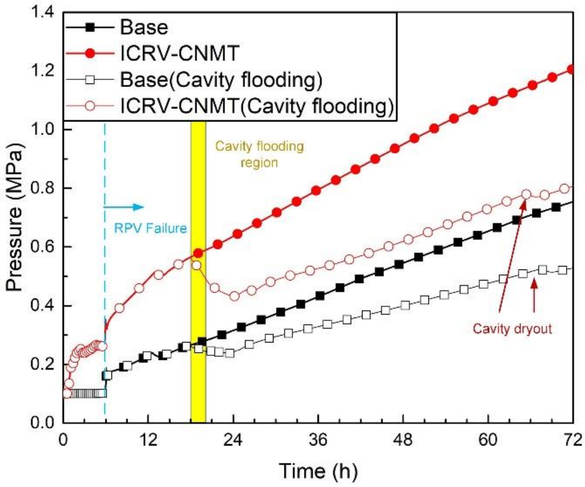

Fig. 5. Effect of cavity flooding in the containment pressure

To reduce the adverse effect of the ICRV, the cavity flooding was conducted. The containment pressure was presented in Fig. 5. The cavity flooding was activated from 64,800 s to 72,300 s and the water of RWT injected total 2,228,573 kg. When the cavity flooding started, the containment pressure decreased by heat removal of the cavity flooding. The pressure was re-increased by the ex-vessel corium. Finally, the containment pressure reached 0.53 MPa and 0.8 MPa in the base-cavity flooding case and the CNMT-cavity flooding, respectively. Certainly, the depressurization of the cavity flooding was confirmed. However, the effect of depressurization was different with the base case and the CNMT case. The pressure was reduced to 0.22 MPa and 0.4 MPa in the base case and the CNMT case, respectively by cavity flooding. It was caused by the difference of the condensate water mass in containment.

4. Conclusion

The conceptual design of the ICRV was investigated using the MELCOR code in SGTR scenario. The steam of the secondary system was released to the upper dome and the RDT. The released mass of the radionuclides was analyzed, and containment pressure was compared in the explored three cases. Major findings in this study and future work can be summarized as follows:

- The in-containment relief valve prevents the release of the radionuclides to the environment.
- And, it increases pressure in containment building because the steam was released to the containment.
- The pressure of the RDT case had higher pressure than upper dome case because of evaporated water in the RDT.
- The overpressure which is adverse effect of the ICRV can be reduced by cavity flooding. The decay heat removal of the cavity flooding causes the depressurization with the steam condensation.
- In the future work, the ex-vessel corium cooling strategy must be investigated for the adverse effects of the ICRV

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