Thermal hydraulic behavior of feeding SG in severe SGTR accident

Youngsu Na* and Sung Il Kim
Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057, Korea
*Corresponding author: ysna@kaeri.re.kr

1. Introduction

In a severe Steam Generator Tube Rupture (SGTR) accident that is one of the bypass scenario, the fission products discharging from the secondary loop of a steam generator (SG) with a ruptured tube can be released into the outside environment. A recent study showed the MELCOR analysis of SGTR in OPR1000 [1]. A decay heat transfers to a SG in a Station Black Out (SBO). Even though a secondary SG shell is supplied with Auxiliary Feed Water (AFW), it becomes to be exhausted. A Safety Relief Valve (SRV) of a pressurizer opens repeatedly due to the increment of the pressure in a primary loop. Water level in a reactor vessel decreases continuously, and core uncovery then causes a severe accident. It is assumed that one SG tube is ruptured by the pressure difference between a primary loop and the atmosphere when an Atmospheric Dump Valve (ADV) on a secondary loop opens. The fission products discharging from a ruptured SG tube would pass through a exhausted secondary SG shell connected with the environment. If we can feed water into a dry shell, the fission products can be released into a pool, and they can be then removed by pool scrubbing. This study introduces the modeling of feeding SG in the previous MELCOR calculation, and we estimate the thermal hydraulic conditions that influences the behavior of the fission products in a wet SG shell.

2. Methods and Results

2.1. SGTR modeling

In a MELCOR calculation, a recent study modeled a hot leg consisting of an upper part and a lower part to simulate a counterflow that could be occurred by natural convection [1]. A coolant flows from a core to a SG through an upper hot leg, and it moves reversely in a lower part. Flow paths between the control volumes of a hot leg include the pump modeling to control a flow rate of a coolant. A hot leg connects with an SG inlet plenum consisting of three control volumes. Mixing of a counterflow in the inlet plenum can influence a flow direction and a flow rate. SG tubes have straight and curved pipes for forward and backward flows.

Figure 1 shows a secondary shell of a SG with two Control Volumes (CV600 and CV610) that connected each other by Flow paths (FL611 and FL612). A SG shell connects with the environment by Flow paths (FL2, FL3, FL4, and FL616) that include four Main Steam Safety Valves (MSSV) and an ADV. The supply of Main Feed Water (MFW) and AFW in the secondary shell of a SG are modeled by the external source of mass and energy. A SGTR is simulated by opening a valve on the Flow path (FL1) that connects between SG straight tubes (CV340) and a lower secondary shell (CV600). When a SGTR occurs, the fission products discharging from a ruptured pipe (FL1) in a diameter of 9.6 mm can be released into a secondary SG shell.

This study used a MELCOR Control Function to control feeding a coolant into a secondary shell. It is assumed that a coolant is supplied at 41500 s with a mass flow rate of 35 kg/s until the water level of 5.58 m. Firstly, we decided the above feeding conditions to neglect a big change comparing with an accident progress without feeding SG. It will help to clearly show that a pool generated in a secondary shell influences the reduction of the fission products released into the environment.

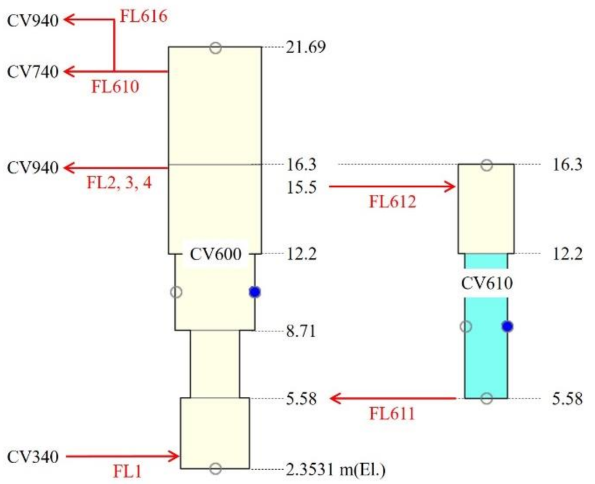

Fig. 1. MELCOR nodalization of a secondary SG shell.

2.2. Thermal hydraulic conditions

In out MELCOR calculation of SGTR with feeding SG, the fission products are released into an exhausted secondary shell during about 3000 s. A SGTR occurs at 38435 s. A pool is generated by feeding a coolant into a secondary shell at 41500 s. This study estimates the thermal hydraulic behavior that can influence a pool scrubbing in a wet secondary shell.

Figure 2 shows the pressure in a SG tube (CV340) and a secondary shell (CV600). The pressure in a SG tube has been fluctuating since opening of a SRV, and it then decreases after feeding SG. The pressure in a secondary shell decreases dramatically by the atmospheric pressure as soon as a ADV opens. It seems that the effect of a SGTR on the pressure in the primary loop is negligible, whereas feeding SG influences the pressure in a SG tube as well as that in a secondary shell.

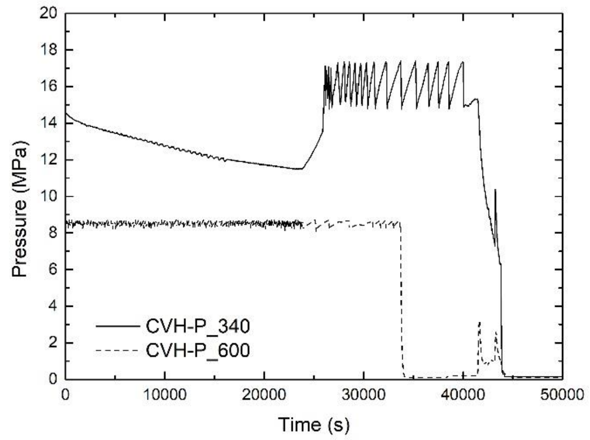

Fig. 2. Pressures in primary and secondary loops.

Feeding SG at 41500 s reduces the temperatures of vapor in a SG tube, vapor and liquid in a secondary shell, as shown in Fig. 3. The pool temperature of 464 K averaged from 41500 s to 43827 s in a secondary shell is about 180 K lower than the atmospheric temperature above a pool, and it is about 50 K lower than the temperature of vapor entering into a pool.

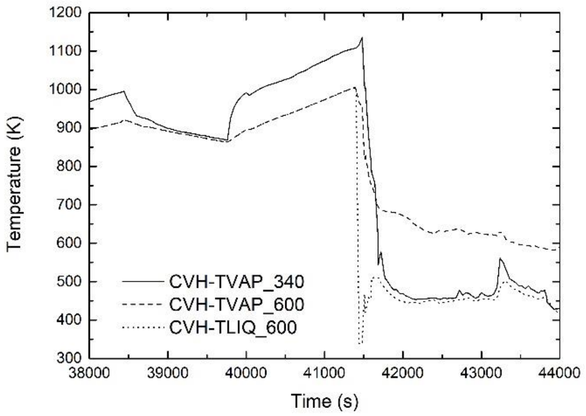

Fig. 3. Temperatures in primary and secondary loops.

Water level in a SG shell reduces continuously, and it has then reached closely the shell bottom located at 2.35 m since 23880 s, as shown in Fig. 4. Open of a ADV at 33722 s makes a secondary shell to be exhausted, and the fission products are then released into a dry shell after a SGTR occurs at 38435 s. Feeding SG generates a pool in the depth of 3.23 m in a shell. A ruptured tube is submerged 3 m below the water level of a pool.

Figure 5 shows the mass flow rates discharging from a ruptured tube (FL1) and releasing into the environment through a ADV (FL616). Vapor in a secondary loop is released into the environment by opening a ADV. When a SGTR is occurred, vapor including the fission products is released into an exhausted shell, and it then flows to the environment through a ADV. Feeding SG at 41500 s causes that the mass flow rate discharging from a shell is much higher than that entering into a shell. Reverse flow from a secondary shell to a primary loop starts as soon as a reactor vessel is penetrated at 43827 s.

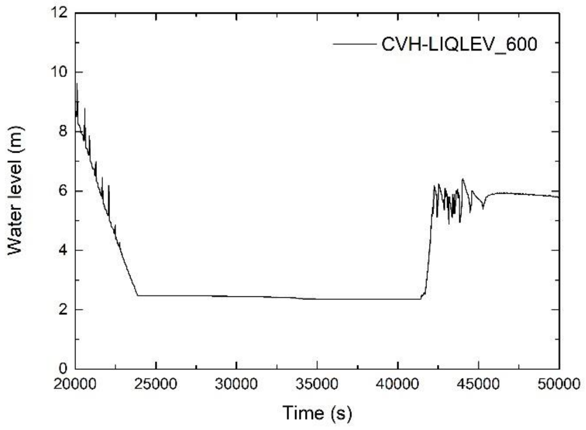

Fig. 4. Water level in a secondary SG shell.

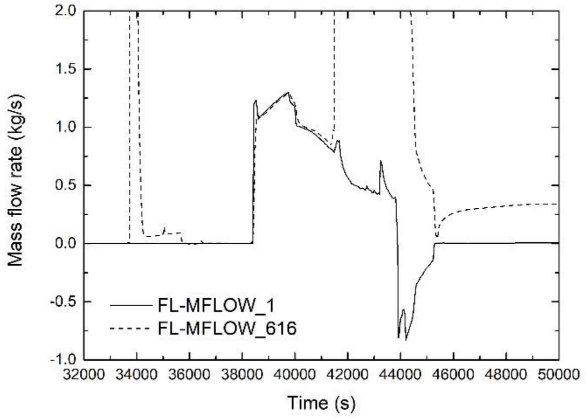

Fig. 5. Mass flow rates at inlet and outlet of a SG shell.

3. Conclusion

This study added feeding SG in a MELCOR calculation of a severe SGTR accident, and it evaluates the thermal hydraulic conditions. To assess the reduction of the fission products in a wet SG shell, we will apply the pool scrubbing and chemistry models to the preceding calculation. It can contribute to suggest an adequate strategy to mitigate a severe SGTR accident.

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[1] S. I. Kim, H. S. Kang, E. H. Ryu, Y. M. Song, and J. Song, MELCOR Analysis on OPR1000 in TI-SGTR scenario, 2019 International Workshop on Post-Fukushima Challenges on Severe Accident Mitigation and Research Collaboration, Daejeon, Korea, November 6-8, 2019.