Assessment of Feeding Strategies in Steam Generator in SGTR Accident

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1. Introduction

Steam Generator Tube Rupture (SGTR) accident is one of the most threaten severe accident scenario because it could cause radionuclides to bypass a containment building, as the last defense barrier. Our previous study assessed a hypothetical accident of SGTR in an Optimized Power Reactor 1000 (OPR1000) using a MELCOR code [1]. Here, Reactor Coolant Pumps (RCPs) stop when Station Black Out(SBO) occurs. The secondary shell of a steam generator becomes empty of water because of decay heat. The pressure in the primary coolant circuit increases, and a Safety Relief Valve (SRV) installed on the top side of a pressurizer then opens and closes over again by its setting pressure. The water level in a reactor vessel decreases, and the core exit temperature increases up to 923 K that is the entry condition of a severe accident. It assumes that an operator opens an Atmospheric Dump Valve (ADV), and one of the steam generator tubes is ruptured by the stress that is induced by the pressure and temperature differences between the primary circuit and the secondary shell. The fission products generated during the core degradation are discharged from the primary circuit through a ruptured tube connecting to an ADV. In a SGTR accident scenario introduced above, if an operator feeds coolant into a secondary shell of a steam generator, a ruptured tube could be submerged. It is expected that the aerosol type of the fission products could be removed by pool scrubbing in the secondary shell. It is necessary to study feeding a SG shell, as a mitigation strategy to reduce the fission products bypassing in a SGTR accident.

2. Methods and Results

To access the behavior of aerosol bypassing under the feeding conditions, we carried out the following research.

2.1. Feeding conditions

The base case without feeding the secondary shell is a SGTR accident induced by opening an ADV under SBO in OPR1000. There was no pool in the secondary shell when one of the steam generator tubes was ruptured. We chose the range of the feeding time from 34000 to 44000 s based on the key accident sequence, such as gap release, SGTR occurrence, and Lower Head Penetration (LHP) of a reactor vessel in the base case, as shown in Table I. The feeding cases can be grouped into the early feeding and late feeding. In addition, we grouped the feeding cases into FRS, FIS, and FBS regarding the location of supplying coolant. Here, FRS and FIS present to inject water into the secondary shell connecting a ruptured SG tube and an intact SG tube, respectively. FBS indicates to supply coolant into the both shells simultaneously. This study assumed that the mass flow rates of water injected into a secondary shell were 5, 10, and 15 kg/s. In four digits of the feeding cases, the first and last two digits present the feeding time and the feeding rate, respectively. We modeled the external source of mass and energy in a SG shell to simulate the feeding conditions using a MELCOR code. Larson-Miller Creep Rupture failure model estimates the occurrence time of SGTR considering the accumulated pipe stress and the temperature of heat structure of a pipe.

2.2. Accident Sequence

This study calculated the base case using a MELCOR code version 2.2.11932. The key accident sequence was as follows: (1) SBO occurred at 0 s, and a reactor then was tripped and a Main Feed Water System (MFWS) was stopped to supply. (2) an ADV was opened at 33724 s. (3) Gap release was started at 34781 s. (4) a SG tube was ruptured at 37867 s. (5) Lower head of a reactor vessel was penetrated at 42590 s.

Table I: Feeding Cases Calculated by a MELCOR Code

Feeding time(s)		Feeding a Ruptured SG shell			Feeding an intacted SG shell			Feeding both SG shells		
		5 kg/s	10 kg/s	15 kg/s	5 kg/s	10 kg/s	15 kg/s	5 kg/s	10 kg/s	15 kg/s
Early feeding	34000	FRS3405	FRS3410	FRS3415	FIS3405	FIS3410	FIS3415	FBS3405	FBS3410	FBS3415
	35000	FRS3505	FRS3510	FRS3515	FIS3505	FIS3510	FIS3515	FBS3505	FBS3510	FBS3515
	36000	FRS3605	FRS3610	FRS3615	FIS3605	FIS3610	FIS3615	FBS3605	FBS3610	FBS3615
	37000	FRS3705	FRS3710	FRS3715	FIS3705	FIS3710	FIS3715	FBS3705	FBS3710	FBS3715
Late feeding	38000	FRS3805	FRS3810	FRS3815	FIS3805	FIS3810	FIS3815	FBS3805	FBS3810	FBS3815
	39000	FRS3905	FRS3910	FRS3915	FIS3905	FIS3910	FIS3915	FBS3905	FBS3910	FBS3915
	40000	FRS4005	FRS4010	FRS4015	FIS4005	FIS4010	FIS4015	FBS4005	FBS4010	FBS4015
	42000	FRS4205	FRS4210	FRS4215	FIS4205	FIS4210	FIS4215	FBS4205	FBS4210	FBS4215
	44000	FRS4405	FRS4410	FRS4415	FIS4405	FIS4410	FIS4415	FBS4405	FBS4410	FBS4415

The occurrence of SGTR and LHP was determined by the feeding conditions, and they were distinguished by colors, such as yellow, light gray, and dark gray in Table I. Both SGTR and LHP did not occur in the feeding cases shown in yellow. Light gray indicates that SGTR occurred but LHP did not occur. SGTR occurred and LHP then came up in the calculated cases shown in dark gray. SGTR could not occur regardless of the feeding conditions, if we injected water into the secondary shell in 2000 s after an ADV opened. It was expected that the fission products did not release into the environment. SGTR did not occur on the FIS cases over 10 kg/s from 2000 to 4000 s after an ADV opened, but the FIS cases at 5 kg/s showed the occurrence of SGTR. In the late feeding time of 38000 and 39000 s, LHP did not occur on the FRS and FIS cases over 10 kg/s or FBS cases, but it could occur at 5 kg/s. LHP occurred on the feeding cases that water was injected at 5 kg/s at 40000 s. LHP did not occur in the FBS cases over 10 kg/s and the FRS cases over 15 kg/s. The fission products could be transported through a ruptured tube submerged at the feeding conditions. It is necessary to access the behavior of aerosol in the secondary shell.

2.3. Mitigation Rate of Cesium Aerosol

The mass of cesium (Cs) aerosol released into the environment was reduced in comparison with that in the base case at the feeding time from 38000 to 40000 s. It depended on the feeding time and injection rate. This study defined the mitigation rate of Cs in the environment, which was calculated by dividing the difference between Cs mass in the feeding case and that in the base case by Cs mass in the base case, as shown in Table II. The mitigation rates increased with the faster and bigger feeding, and they became to be similar over 10 kg/s. In addition, this study showed the FBS cases had the biggest mitigation rate, and the mitigation in the FRS cases was higher than that in the FIS cases. Cs mass in the FRS at 5 kg/s and 42000 s case was not reduced.

Table II: Mitigation rate of Cs in the FRS cases

Feeding time(s)	Feeding mass flow rate (kg/s)		
	5	10	15
38000	-82%	-99%	-99%
39000	-80%	-98%	-98%
40000	-53%	-81%	-89%
42000	0%	-3%	-6%
44000	0%	0%	0%

In the FRS3805 case, the water level in the SG shell was kept from 0.1 to 0.2 m, even though water was injected continuously into the SG shell, as shown in Fig. 1. It is expected that there will be little effect of pool scrubbing, because the water level is below the elevation of a ruptured tube. Temperature of steam discharging from a ruptured tube was about 100 K higher than the atmospheric temperature existing in the SG shell. Water injecting into a SG shell could be evaporated by higher atmospheric temperature. It can cause the water level to be fluctuated. A MELCOR code could calculate the aerosol mass removed by steam evaporation, even though there is little effect of pool scrubbing.

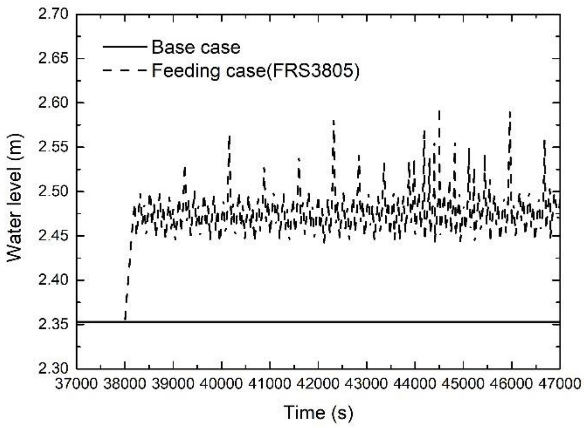

Fig. 1. Water level of the SG shell.

3. Conclusion

This study calculated that the feeding strategies in a steam generator could influence the accident sequence and the bypassing behavior of the fission products in a hypothetical scenario of SGTR in OPR1000 using a MELCOR code of version 2.2.11932. In the base case, SGTR was occurred by opening an ADV in SBO. In the feeding cases, the injection locations were a ruptured SG shell, an intact SG shell, and both SG shells, and the range of feeding time and flow rate were 34000~44000 s and 5~15 kg/s, respectively. Accident sequences of the base and feeding cases were calculated and compared each other. SGTR did not occur regardless of feeding conditions when injecting water into a SG shell in 2000 s after an ADV opens. Decay heat in the primary circuit could be removed by the early feeding. The mitigation rates of Cs aerosol in the environment increased at the faster and bigger feeding. The mitigation rate of feeding water into a ruptured SG shell was higher than that into an intact SG shell. This result can contribute to find the adequate strategies in a SGTR accident scenario.

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