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Study of Multiple Steam Generator Tube Rupture Event in Shin-Kori Units 1&2

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1. Introduction

After the Fukushima nuclear accident, beyond design basis conditions has played an important role for developing the reactor coolant system (RCS) cooldown strategy and recovery action. Additional failures of the safety components are also considered in terms of sufficient safety margin with application of proper emergency operating procedures [1].

The multiple steam generator tube rupture (MSGTR) as one of the prescribed multiple failure accidents is an event in which multiple U-tubes in one steam generator are ruptured at the same time. When MSGTR accident happens in OPR1000, operator needs to take proper action to terminate primary coolant discharge to steam generator secondary side and to suppress the amount of radionuclide release to environment as low as possible.

2. Analysis Information

The MSGTR event is described as follows. Once the accident was initiated, the reactor coolant start to leak to the secondary system. The reactor trip signal is generated by the hot-leg saturation temperature or low pressurizer pressure signal. The leaked reactor coolant mixed with the feedwater could be sent to the condenser or released to atmosphere through the main steam safety valves (MSSVs). Since the released gas contains radioactive materials, the MSSVs lift time is one of the important factors to protect people and environment during MSGTR event.

The MSGTR event is assumed the five tubes rupture at the hot-leg side. Two different scenarios of the MSGTR were considered dependent on the recovery actions taken by operator.

2.1 Simulation method

The RELAP5/Mod3.3 code is used to analyze the thermal hydrodynamic behavior of MSGTR event in transient period [2]. The nodalization diagram of Shin-Kori Units 1&2 is shown in Fig. 1. The steam generator (SG) U-tubes were modeled as two separate region for simulating the ruptured tube.

2.2 Steady state analysis

The steady state calculation was performed in order to obtain appropriate initial conditions prior to the initiation of the MSGTR accident. The comparison of plant design values and steady state simulation results is shown in Table 1. The calculation error is within 0.6%. It indicates that the major parameters of the primary and secondary system correspond closely to the real plant conditions.

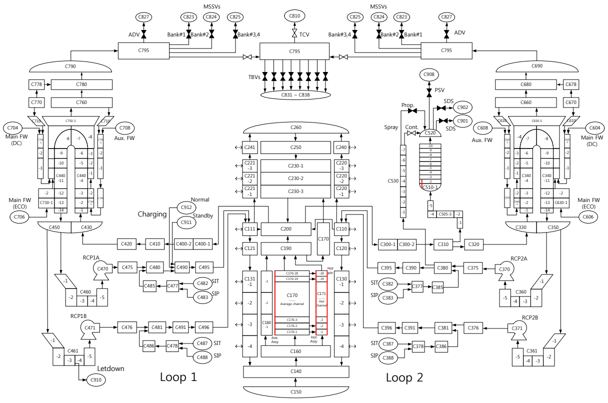

Fig. 1. Nodalization diagram of Shin-Kori Units 1&2.

Table 1. Initial conditions for MSGTR.

Parameter	Design value	Steady state value
Core power (MWt)	2815	2815
Pressurizer pressure (MPa)	15.5132	15.5201
Pressurizer level (%)	52.60	52.51
Hot-leg temperature (ºC)	327.23	327.20
Cold-leg temperature (ºC)	295.83	295.89
RCS flow rate (kg/s)	15308.7	15298.1
Steam dome pressure (MPa)	7.5429	7.5150
Total FW flow per SG (kg/s)	802.9	798.3
SG level (%WR)	79	79
Circulation ratio	3.7	3.7

3. Analysis Result

3.1 No operator action case

Fig. 2 shows the break flow of the ruptured tube in the no operator action case. The break flow decrease as reduction of the pressure difference between primary and secondary systems. The reactor trip occurs at 140 seconds due to the signal of the hot-leg saturation temperature generated by a decrease of the RCS pressure.

The RCS was rapidly depressurized after the reactor trip and reached a safety injection set point as shown in Fig. 3. The steam in the SGs was released to condenser through the steam bypass control system (SBCS).

In Fig. 4, the level of affected SG rapidly increase due to the leak flow from the primary side through the break tubes. The main steam isolation signal (MSIS) is generated by the high steam generator level. The MSSV was first opened at 1351 seconds as shown in Fig. 5. The core decay heat can be removed by the regular open of MSSVs, but an atmospheric release of the radioactive inventory arises.

The cladding temperature in the no operator action case is depicted in Fig. 6. After the reactor trip, the temperature is dropped sharply and then maintained without heating fuels. Which means that core damage is prevented with sufficient core cooling capability.

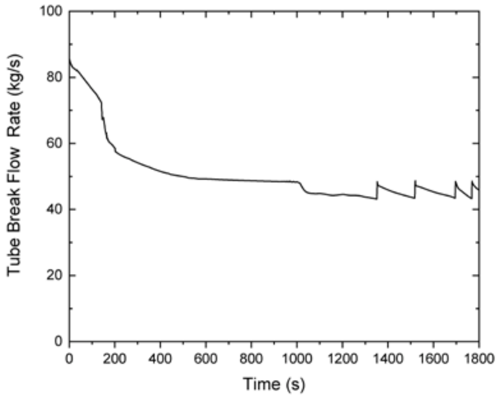

Fig. 2. SG tube break flow rate

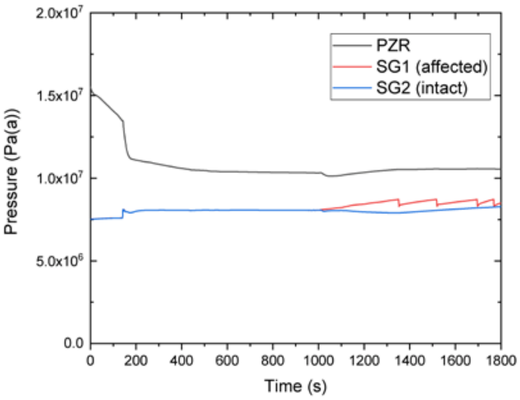

Fig. 3. Primary and secondary pressures

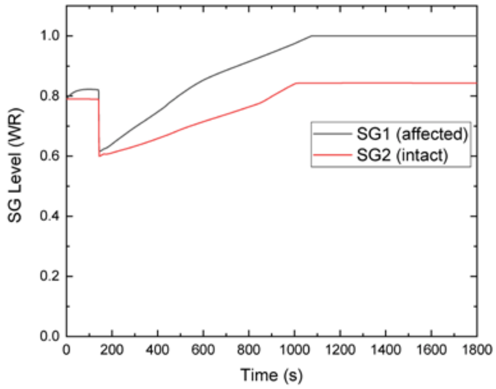

Fig. 4. SG level

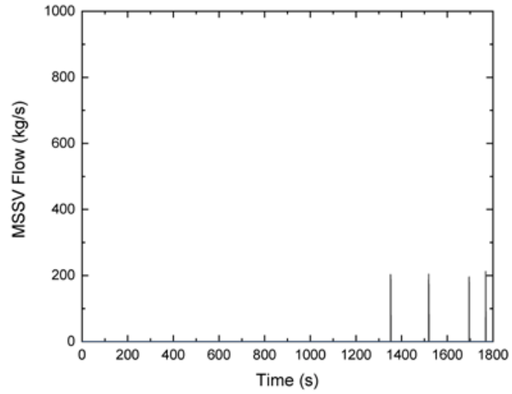

Fig. 5. MSSV flow rate

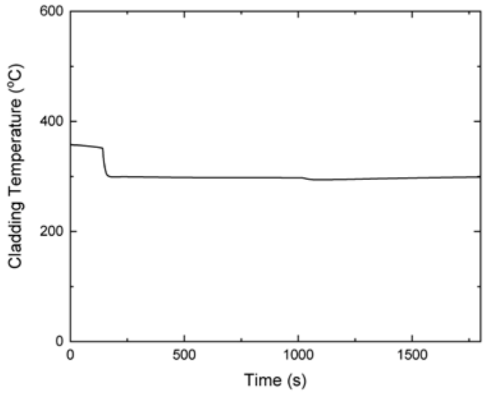

Fig. 6. Cladding Temperature

3.2 Operator recovery action case

To mitigate the consequence of the event, operator action is performed to isolate the affected SG as soon as possible and minimize the amount of the radioactive material release to atmosphere through MSSVs. Refer to the no operator action case and Emergency Operation Guideline, EOG-05, the following recovery actions will be taken in the MSGTR event.

- Stop one RCP per a loop in 10 minutes after the reactor trip
- Operate the reactor coolant gas vent system (RCGVS)
- Control atmosphere dump valve (ADV) of the intact SG for cooldown of RCS within the rate of 100°F/hr
- Control high pressure safety injection (HPSI) flow manually

Fig. 7 presents the break flow in case of the operator recovery action taken. The pressure of the primary system could be adjusted by manual control of the HPSI flow based on the pressurizer level. The break flow oscillates, but approaches zero. It is because the pressures between primary system and the affected SG can stay about the same by the manual control of HPSI flow and ADV in the intact SG as shown in Fig. 8.

The collapsed level of the affected SG rises faster than that of the intact SG because of the break flow from the primary side as shown in Fig. 9. The level of the intact SG begins to decline because of ADV open for RCS cooldown.

Fig. 10 shows the MSSV opening of the operator recovery action case. The MSSVs were repeatedly opened and closed until completing depressurization of the primary pressure. Afterwards, the pressures of the primary and secondary systems will be controlled by ADVs in the intact SG. 20 minutes after the accident, the RCGVS valve was opened by operator action. Fig. 11 represents the flow rates of RCGVS depending on the pressure of the pressurizer.

The cladding temperature in case of the operator recovery action taken is depicted in Fig. 12. The fuel heat-up does not occur during the MSGTR event due to appropriate RCS cooldown and depressurization by operators.

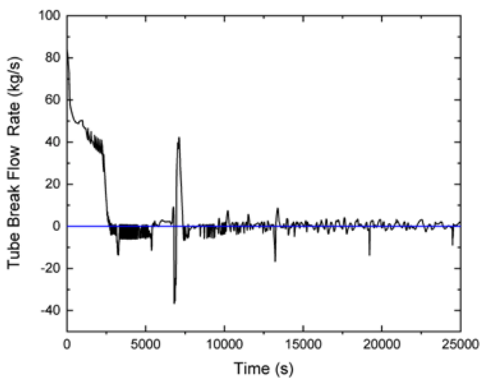

Fig. 7. SG Tube break flow rate

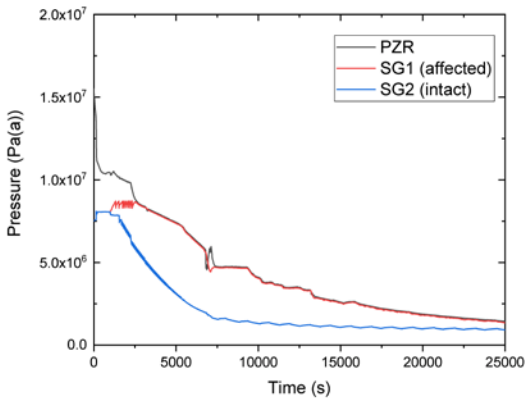

Fig. 8. Primary and secondary pressures

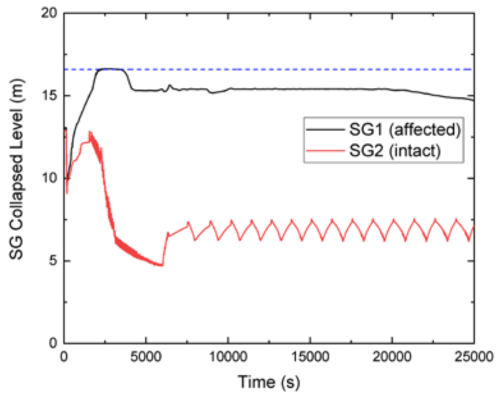

Fig. 9. SG collapsed levels

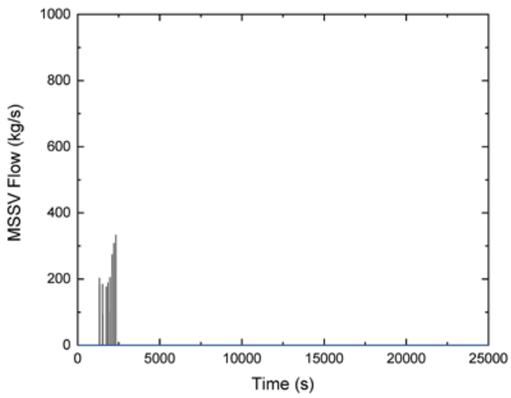

Fig. 10. MSSV flow rate

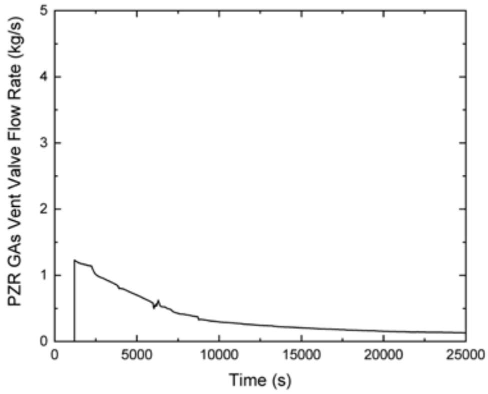

Fig. 11. RCGVS flow rate

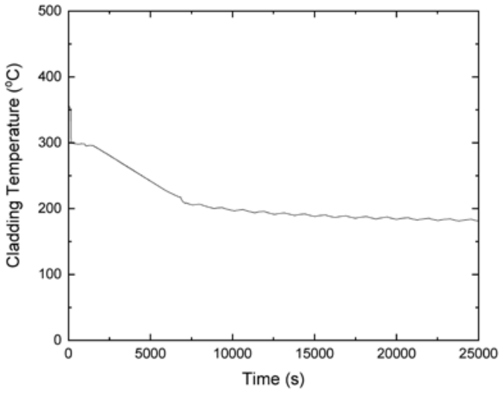

Fig. 12. Cladding Temperature

4. Conclusions

In this study, we compared two different cases dependent on the recovery actions taken by operators in the MSGTR event. The RELAP5/Mod 3.3 code was used to obtain the thermal hydrodynamic behaviors of the event. In the no operator action case, the MSSV was first opened at 1351 seconds. In case of the operator recovery action taken, the opening of MSSVs was terminated early in the event by control of ADVs in the intact SG. It contributed to reducing the release of the radioactive inventory.

Both cases had sufficient core cooling capability and the fuel heat-up did not occur during the entire event. Therefore, core damage was prevented in the MSGTR event in Shin-Kori Units 1&2. In the future, the radiation dose calculation during the MSGTR event will be studied.

REFERENCES

[1] Korea Hydro and Nuclear Power Co. Ltd., "Development of Design Extension Conditions Analysis and Management Technology for Prevention of Severe Accident Report", September, 2017.
[2] RELAP5/MOD3.3 Code Manual, ISL, 2016.