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Sensitivity Analysis of Operator Recovery Actions for Multiple Steam Generator Tube Rupture Event in OPR1000

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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 plant, 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.

In this study, we pay attention to how the operator recovery actions can mitigate the consequence of the MSGTR event. Operators have to take proper actions following the emergency operating guideline to terminate a discharge of primary coolant to steam generator secondary side and to suppress the amount of radionuclide release to environment as low as possible during the event. This study thus attempts to find out the effects of the starting time of the operator recovery actions.

2. Modeling Information

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 in LOOP 1 were modeled as two separate region for simulating the ruptured tube. The MSGTR event assumed five tubes rupture at the hot-leg side. The MSGTR was considered dependent on the recovery actions time taken by operator.

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

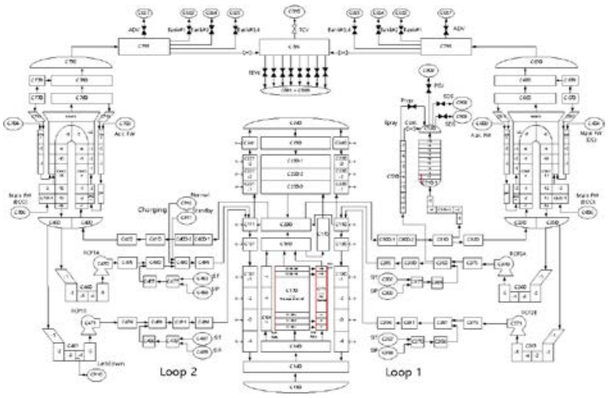

Fig. 1. Nodalization diagram of OPR1000.

3. Sensitivity Analysis

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. According to Emergency Operation Guideline, EOG-05, following recovery actions will be taken in the MSGTR event.

- Stop one RCP per a loop in 10 minutes after the reactor trip
- Open the main steam isolation bypass valve (MSIBV) of the affected SG (15, 20, 30 min)
- Reduce RCS pressure with the auxiliary spray and the reactor coolant gas vent system (RCGVS) (15, 20, 30 min)
- Control atmosphere dump valve (ADV) of the intact SG for cooldown of RCS (15, 20, 30 min)
- Control high pressure safety injection (HPSI) flow manually

Figs. 2 to 5 present thermal hydrodynamic behaviors of the MSGTR event with the operator recovery actions. The break flows for all analysis case are compared in Fig. 2. 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. 3. The RCS liquid temperature shows a similar tendency with the primary system pressure presented in Fig. 4. Case 1, 2 and 3 reach the shutdown cooling system (SCS) entry condition at about 4,000, 5,000 and 7,000 seconds in the event. The faster starting time of the operator recovery actions has the faster entry time for SCS operation.

The effects of the starting time of the operator recovery actions on the MSSV opening time are depicted in Fig. 5. If the recovery actions are performed within 15 minutes, the MSSVs are not opened during the MSGTR event. In Case 2 with 20 minutes of the recovery starting time, MSSVs open once in the event. The rest of the cases shows that the MSSVs repeat open and close before operator recovery actions start.

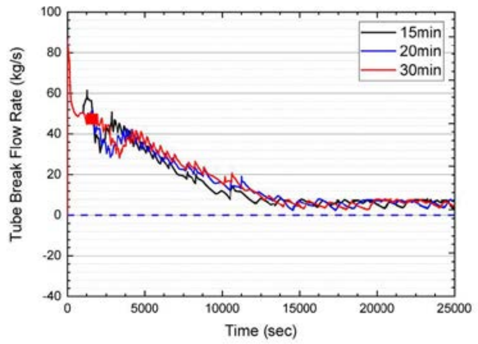

Fig. 2. SG Tube break flow rate

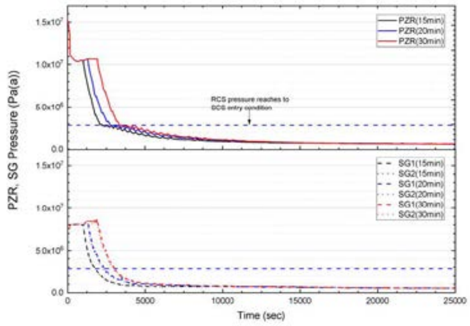

Fig. 3. Primary and secondary pressures

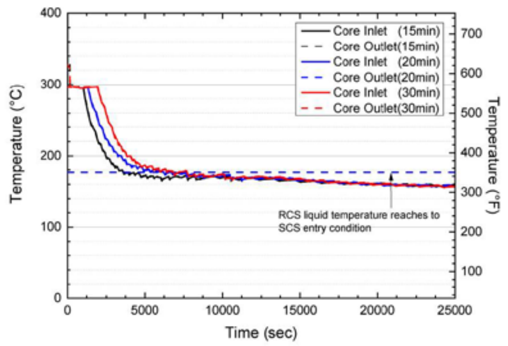

Fig. 4. RCS temperatures

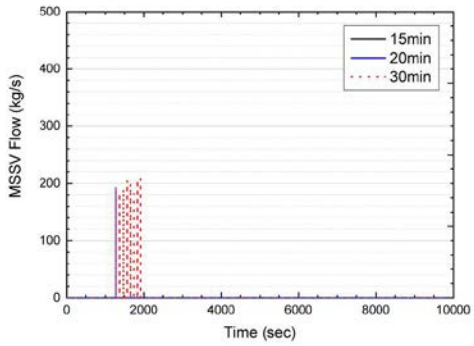

Fig. 5. MSSV flow rate

4. Conclusions

We studied sensitivity analysis of the effects of the recovery actions time taken by operators on the MSGTR event. Considering operator recovery actions, the opening of MSSVs was terminated early in the event by controlling auxiliary spray and RCGVS in PZR, the ADVs in the intact SG and the MSIBV in the affected SG. It contributed to prevent the release of the radioactive materials. From the result, if the operator recovery action was taken before 15 minutes, the MSSV will not open and there will be no radiative release. The faster starting time of the operator actions has the faster entry time for SCS operation. Also, the operator recovery actions contribute that the system has 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 OPR1000.

ACKNOWLEDGMENTS

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[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.