Thermal-Hydraulic Analysis of MSGTR event in OPR1000 using SPACE code

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1. Introduction

After the Fukushima accident, the importance of nuclear power plants safety in extreme events such as design extended condition (DEC) has greatly emphasized. DEC is considered as accidents due to multiple failures of the safety component and severe accidents [1].

The multiple steam generator tube rupture (MSGTR), one of the multiple failure accidents, is an event in which two or more u-tubes are ruptured in one steam generator at the same time. In the case, the operator must quickly control the water level of the steam generator (SG) in broken side and perform depressurization to minimize the amount of radionuclide release to environment.

In this paper, thermal-hydraulic analysis of MSGTR accident with application of operator action on OPR1000 was performed using SPACE code.

2. Method of Analysis

2.1 SPACE Modeling of the MSGTR

The SPACE is transient analysis code for design of nuclear power plant [2]. Fig. 1 shows OPR1000 nodalization in the SPACE code. The MSGTR was assumed five u-tubes rupture at the hot-leg side in a loop with a pressurizer (PZR). The SG u-tubes in broken side were modeled as two regions for simulate MSGTR.

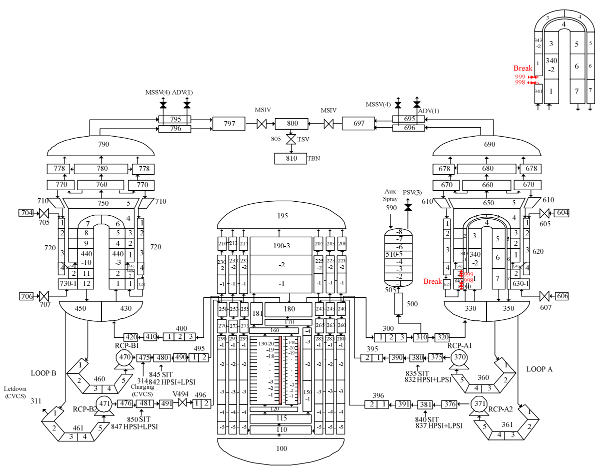

Fig. 1. OPR1000 nodalization for MSGTR analysis

2.2 Steady-State analysis

Table 1 shows a comparison of the major parameters of the design value and steady-state calculation result of OPR1000 at normal operating condition. The major parameter error between design value and SPACE 3.2 is within 0.2%.

Table 1. Comparison of OPR1000 normal operating condition with SPACE results

Parameter	Design value	SPACE 3.2
Core power (MWt)	2815	2815
PZR pressure (MPa)	15.51	15.55
PZR level (%)	52.6	52.6
Hot-leg temperature (K)	600.48	602.25
Cold-leg temperature (K)	568.98	571.49
RCS flow rate (kg/s)	15308.66	15316.97
Steam dome pressure (MPa)	7.38	7.38
SG wide range level (%)	79.0	79.0
Total SG feedwater (kg/s)	801.32	800.99

3. Results of Analysis

The MSGTR analysis was performed for the case with and without the operator action.

3.1 Case: without operator action

Once an accident occurred in an initial condition, the coolant of the primary system was released to the secondary system through the broken point. Fig. 2 is shows break flow of broken point. The break flow was decreased by reduction of pressure difference between primary system and secondary system in broken side.

System pressure is shown in Fig. 3. Primary system pressure was quickly decreased by reactor trip signal at 91 seconds. The reactor trip signal was generated by the hot-leg saturation temperature signal. After that reactor trip, the SG pressure was increased, and the radionuclide was released to the environment through the main steam safety valves (MSSVs) or to the condenser by the steam bypass control system (SBCS).

Fig. 4 shows SG water level. SG water level in the broken loop was rapidly increased due to break flow from primary system. Main steam isolation system (MSIS) signal is generated by high SG water level signal at 683 seconds. Broken SG water level exceeds full level at 738 seconds and the MSSV opens for the first time at 905 seconds. The MSSV flow rate is shown in Fig. 5.

Table 2 shows the sequence of event for without operator action.

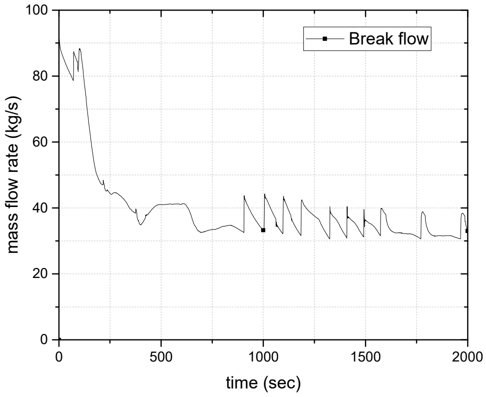

Fig. 2. Break flow rate for case without operator action

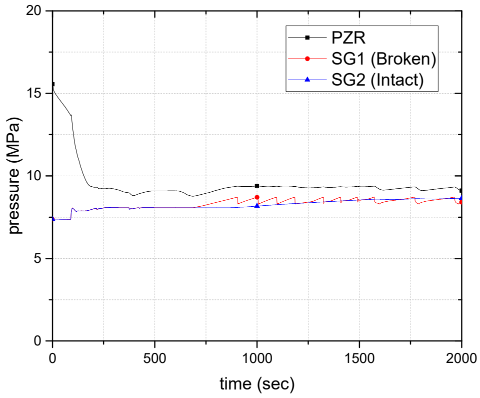

Fig. 3. System pressure for case without operator action

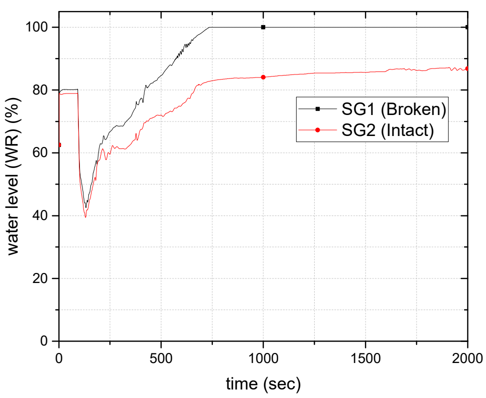

Fig. 4. SG water level for case without operator action

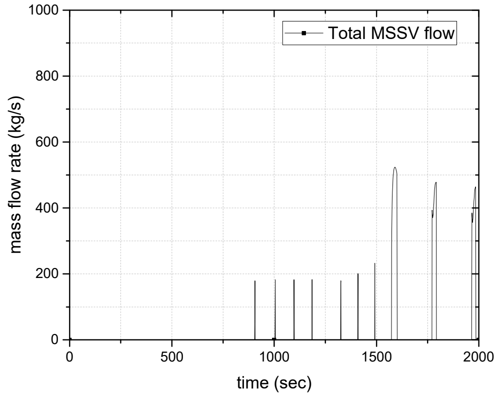

Fig. 5. Total MSSV flow rate for case without operator action

Table 2. Sequence of event for case without operator action

Event	Time
MSGTR occur	0.0
Reactor trip by hot-leg saturation temperature signal	91.0
HPSI start	138.0
MSIV & MFIV close	683.0
Full water level of the broken SG	738.0
First open of MSSVs	905.0
End calculation	2000.0

3.2 Case: with operator action

In the case, the following operator actions were applied with reference to emergency operation guideline (EOG).

- Stop one RCP per a loop in 600 seconds (10 minutes) after the MSGTR occur
- Control the main steam isolation bypass valve (MSIBV)
- Operate the auxiliary spray of PZR and steam generator blowdown (SGBD)
- Control the atmosphere dump valve (ADV) of the intact SG for RCS cooling condition within rate of 56℃/hr
- Manual operation of HPSI under PZR water level condition

Fig. 6 shows the break flow for operator action case. In the early part of transient, break flow was reduced due to the manual operation of the HPSI according to the PZR water level. After interruption HPSI, break flow changed depending on the PZR auxiliary spray operation since it was greatly affected by the pressure difference between the primary and secondary system.

As shown in Fig. 7, the pressure of primary and secondary system in broken loop was reduced while maintaining a constant pressure difference due to PZR auxiliary spray and the intact SG pressure was gradually decreased due to opening of the ADV.

System water level is shown in Fig. 8. The collapsed water level of broken SG was rapidly increased by break flow from primary system and maintained in the range of 70 to 90 % by the SGBD. The intact SG water level was decreased due to ADV open for RCS cooldown and maintained in the range 15 ~ 40 % by auxiliary feedwater. The PZR water level was rapidly decreased by break flow to secondary system and maintained in the range 15~33 % by HPSI and charging flow.

Fig. 9 shows total MSSV flow rate. MSSV flow rate was zero due to MSIBV opening.

Reactor coolant system (RCS) average temperature is shown in Fig. 10. RCS average temperature was reduced due to ADV opening until shutdown cooling system (SCS) entry temperature.

Table 3 presents the sequence of event for case with operator action.

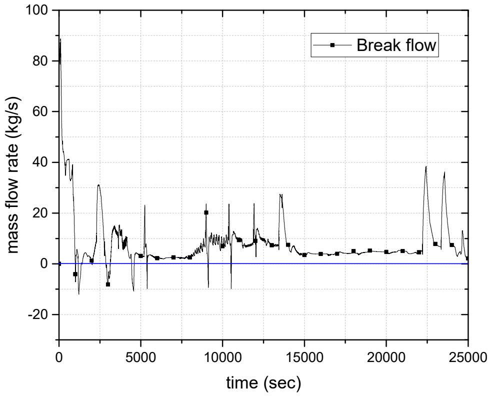

Fig. 6. Break flow rate for case with operator action

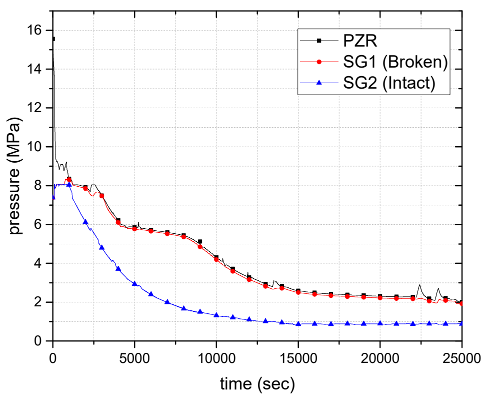

Fig. 7. System pressure for case with operator action

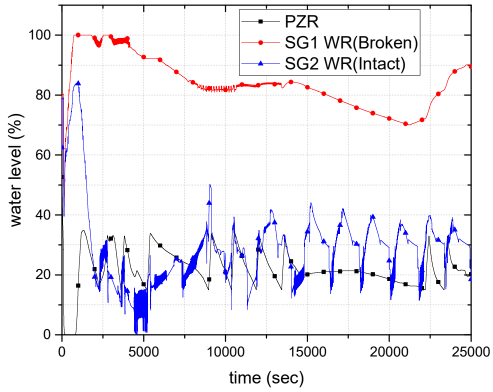

Fig. 8. System level for case with operator action

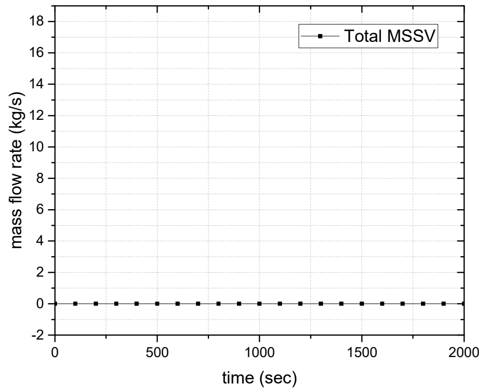

Fig. 9. MSSV flow rate for case with operator action

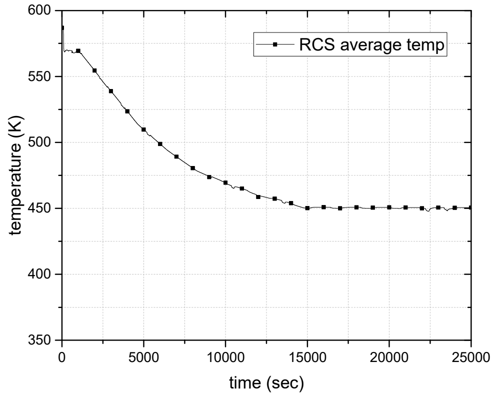

Fig. 10. RCS average temperature for case with operator action

Table 3. Sequence of event for case with operator action

Event	Time
MSGTR occur	0.0
Reactor trip by hot-leg saturation temperature signal	91.0
HPSI start	138.0
Stop one RCP per a loop	600.0
MSIV & MFIV close	756.0
Full water level of the broken SG	840.0
First open of MSIBV	855.0
First operation of PZR auxiliary spray and SGBD	915.0
Opening of ADV	1056.0
HPSI manual control start	1167.0
Decrease of SG water level below full water level	1784.0
Satisfaction of SCS operating conditions	22313.0
End calculation	25000.0

4. Conclusions

The MSGTR analysis was performed in two cases depending on operator action. In the case without operator action, the MSSVs opened because of high SG pressure. Also, broken SG water level was maintained at 100% for wide range level. In the case with operator action, broken SG water level was maintained within a permissible range of EOG. The MSSVs didn't open in this event. It was confirmed that major thermal-hydraulic parameters satisfied the SCS conditions. Therefore, through operator action, the RCS coolant cooling and RCS depressurization performances were confirmed.

ACKNOWLEDGEMENT

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[1] IAEA, Safety of Nuclear Power Plants: Design, SSR-2/1, Rev.1, 2012
[2] SPACE 3.2 User Manual, KHNP, 2018.