Preliminary Calculation of SGTR with HPSI Failure in OPR1000 using SPACE Code

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1. Introduction

After Fukushima Nuclear Power Plant (NPP) accident, ensuring the safety of NPPs when Beyond Design Basis Accidents (BDBAs) occur has become a worldwide issue. In Korea, as the nuclear safety act was revised, DBDAs and severe accidents (SAs) have been considered for the operating NPPs and designing new NPPs since June 2015 [1]. For that reason, a number of researches about the DECs (Design Extension Conditions) which include DBDAs and SAs have been carried out to prevent the damage on reactor core and the emission of radioactivity material to the public.

In this paper, we studied on the thermal-hydraulic behavior while a steam generator tube rupture (SGTR) accident and the high pressure safety injection (HPSI) failure accident occur at the same time in OPR1000 using SPACE (Safety and Performance Analysis Code for Nuclear Power Plant) v3.2 [2].

2. SPACE Input Model

Fig. 1 shows the nodalization of OPR1000 for SPACE code. This nodalization was developed for steady state condition. In order to analyze the SGTR with HPSI failure accident, we assumed that the single U-tube guillotine break occurs at hot leg side in steam generator (SG) #2. After then, the calculation nodes of U-tubes in SG #2 were separated into a broken tube and intact tubes. For the transient calculation, some components such as the turbine bypass valves (TBVs), the pressurizer (PZR) auxiliary spray were added. The calculation result of the modified input model is summarized in Table I.

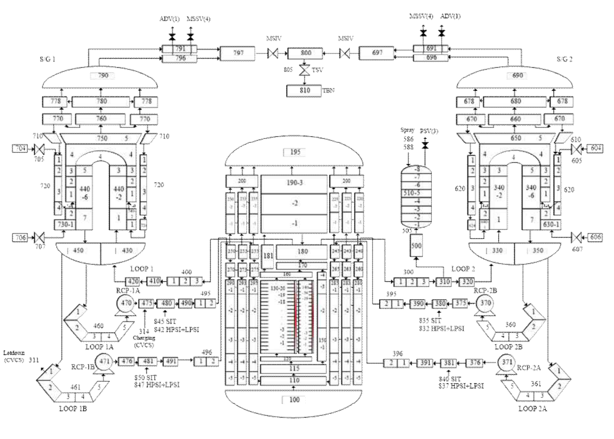

Fig. 1. Nodalization of OPR1000 for SPACE code

Table I. Calculation result of steady state condition

Parameter	Location	Design value	SPACE v3.2	Error (%)
Reactor Coolant System				
Power (MW_{th})	100 %	2815.0	2815.0	0.00
Pressure (MPa)	PZR	15.51	15.55	0.28
Level (%)	PZR	52.6	52.62	0.04
Flow rate (kg/s)	RCS	14848.77	14866.73	0.12
Temperature (K)	Hot leg	600.48	602.25	0.29
	Cold leg	568.98	571.49	0.44
Secondary System				
Pressure (MPa)	Steam dome	7.38	7.38	0.01
Level (%NR)	SG #1, 2	44.0	43.9	-0.15
MFW flow rate (kg/s)	SG #1, 2	801.32	802.32	0.12

3. Calculation Results

3.1 Case 1: without operator actions

When a SGTR accident was initiated, in case of the reactor coolant system (RCS), the pressure and the inventory decreased as shown in Fig. 2 and 3. As the RCS pressure was reduced, the hot leg saturated temperature reactor trip signal occurred at 841 sec. Also, the turbine trip signal occurred almost at the same time. After the reactor trip, the break flow from the RCS to the secondary system was reduced as a result of the decline of pressure difference as shown in Fig. 4. The hot legs temperature decreased sharply to that of cold legs as shown in Fig. 5. As the RCS pressure decreased, the safety injection actuation signal was activated at 858 sec, but there was no HPSI flow in this study.

In the secondary system, as shown in Fig. 3, the water level of SGs decreased sharply due to the pressurization caused by the turbine trip. After then, the water level increased as a result of the reduction of the heat transfer from the RCS and the injection of the main feedwater into the downcomer of SGs. The increment of SG #2 water level alarmed the high steam generator level signal, and the signal occurred the main steam and the feedwater isolation signals at 1767 sec. The steam in SGs secondary side was emitted to the condenser through the TBVs between the period of the turbine trip and the main steam isolation. After the main steam isolation valves (MSIVs) were closed, the steam dome pressure increased up to the main steam safety valves (MSSVs) set-point and was regulated by the open and shut of MSSVs after 2072 sec. When the MSSVs were open, the water level of SGs tended to decrease rapidly. The flow rate of MSSVs can see in Fig. 6. The sequence of event is summarized in Table II.

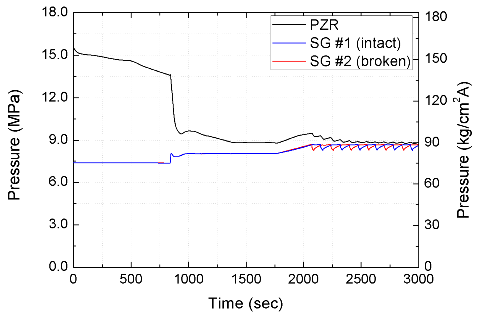

Fig. 2. System pressure (w/o operator actions)

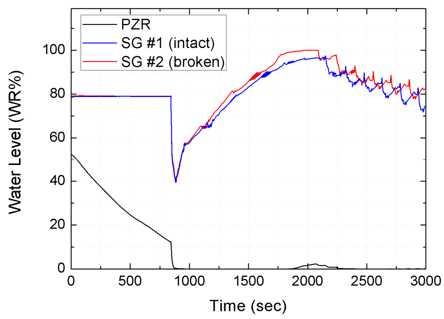

Fig. 3. Water level (w/o operator actions)

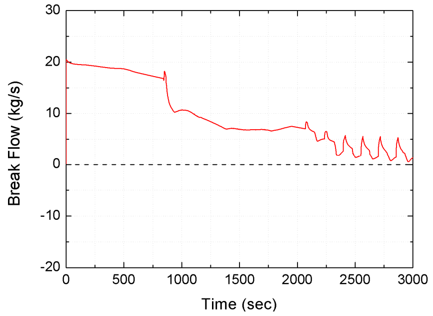

Fig. 4. Break flow (w/o operator actions)

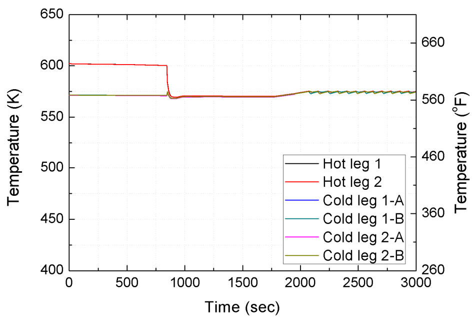

Fig. 5. RCS temperature (w/o operator actions)

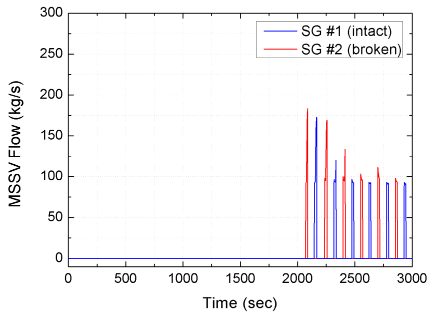

Fig. 6. MSSV flow (w/o operator actions)

Table II. Sequence of event (w/o operator actions)

Time (s)	Event
0	Initiation of SGTR
841	Reactor trip by hot leg saturated temperature signal
	Turbine trip
842	First open of TBVs
858	Safety injection actuation signal (No HPSI injection)
1767	Main steam isolation
	Main feedwater isolation
2072	First open of MSSVs
3000	End of calculation

3.2 Case 2: with operator actions

3.2.1. Mitigation strategy

In order to mitigate the accident result, we set up some operator actions as follow:

i) Turn off a reactor coolant pump (RCP) per a loop and all PZR heaters.
ii) Regulate steam dome pressure of affected SG using main steam isolation bypass valve (MSIBV) to prevent the MSSVs opening.
iii) Operate the PZR auxiliary spray to de-pressurize RCS to satisfy the shutdown cooling system (SCS) entry condition.
iv) Operate the PZR auxiliary spray to regulate the water level of affected SG by forming backflow.
v) Operate the main steam atmosphere dump valves (MSADVs) of intact SG side within 56 ^{o}C/hr cooling rate to cooldown RCS.

3.2.2. Calculation results

In this analysis, we assumed that it takes 30 minutes for operators to recognize the accident and 1 minute to conduct an action. Fig. 7~11 shows the system pressure, RCS temperature, water level, break flow, and steam flow of MSIBV and MSSVs, respectively.

Firstly, at 1800 sec, two RCPs and all PZR heaters were turned off by the operators. After then, at 1896 sec, there was the first opening of MSIBV. Because the SG #2 pressure was maintained below MSSVs set-point by the MSIBV, the MSSVs were kept closed as shown in Fig. 11.

The SG #2 was fully filled with the coolant during 1910~2089 sec as shown in Fig. 9. At 1956 sec, the time after 60 sec from the MSIBV open, the PZR auxiliary spray began to work for de-pressurization of RCS. When the RCS pressure was lower than SG #2 pressure due to the operation of PZR auxiliary spray, the backflow to RCS was formed as shown in Fig. 10. We confirmed that operating PZR auxiliary spray was effective on the recovery of RCS inventory, the control of water level of SG #2, and de-pressurization of the RCS in Fig. 7 and Fig. 9.

After 60 sec, at 2016 sec, the MSADVs of SG #1 side began to be operated to cooldown the RCS within

56°C/hr rate as shown in Fig. 8. When the MSADVs were opened, the water level of SG #1 decreased rapidly. The water level of SG #1 was maintained in a certain range by the opening of MSADVs and the injection of auxiliary feedwater as can see in Fig. 9.

As a result of the operator feedback actions, every SCS entry conditions were satisfied at 19326 sec. The sequence of event of this case is summarized in Table III.

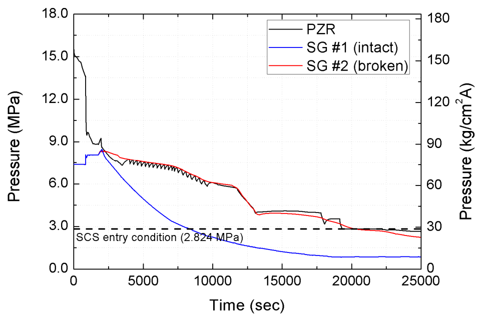

Fig. 7. System pressure (w/ operator actions)

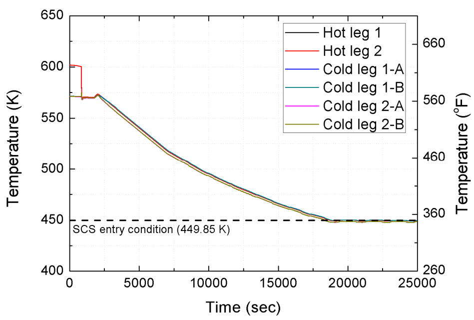

Fig. 8. RCS temperature (w/ operator actions)

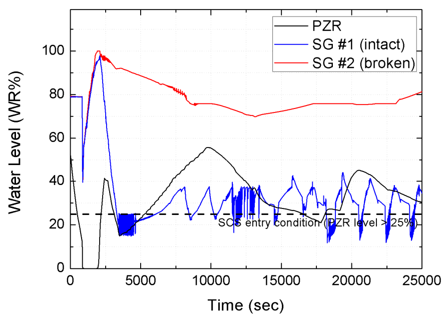

Fig. 9. Water level (w/ operator actions)

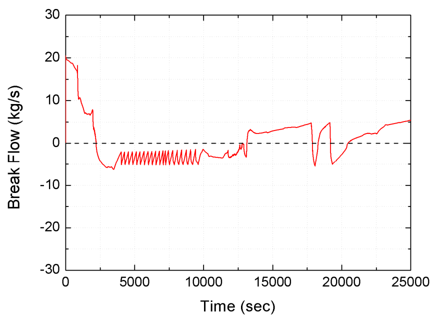

Fig. 10. Break flow (w/ operator actions)

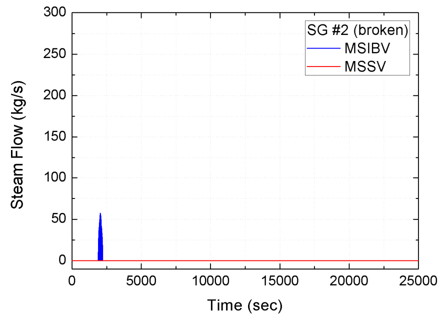

Fig. 11. MSIBV and MSSVs flow (w/ operator actions)

Table III. Sequence of event (w/ operator actions)

Time (s)	Event
0	Initiation of SGTR
841	Reactor trip by hot leg saturated temperature signal
	Turbine trip
842	First open of TBVs
858	Safety injection actuation signal (No HPSI injection)
1767	Main steam isolation
	Main feedwater isolation
1800	Turn off RCPs and PZR heaters
1896	MSIBV open (SG #2)
1956	First operation of PZR auxiliary spray
2016	Operation of MSADVs (SG #1)
3382	Injection of Auxiliary feedwater (SG #1)
19326	Fulfillment of SCS entry conditions
25000	End of calculation

4. Conclusions

In this study, we carried out the transient calculations of the SGTR with HPSI failure accident using SPACE v3.2 code.

According to the calculation results, when the operator feedback action was absent, the reactor core was cooled by the open and shut of MSSVs, and the SCS entry conditions were not satisfied. On the other hand, when operators conduct some actions mentioned at the before chapter, we confirmed that the thermal-hydraulic conditions of the RCS and secondary system satisfied the SCS entry conditions without the opening of MSSVs.

As a further study, because the backflow can reduce the boron concentration in RCS, it seems that we need to carry out the additional analysis about the reactivity.

ACKNOWLEDGEMENT

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REFERENCES

[1] Nuclear Safety Act, Korea Ministry of Government Legislation, 2018.

[2] SPACE 3.2 User's Manual, KHNP, 2018.