# Preliminary Assessment of SPACE code for SBLOCA with HPSI failure in OPR1000

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## 1. Introduction

After Fukushima nuclear power plant accident, International Atomic Energy Agency (IAEA) has introduced Design Extension Conditions (DECs) which includes Beyond Design Basis Accidents (BDBAs) and Severe Accidents (SAs) with SSR-2/1(2012) and has demanded complementary measures, accident managements and off-site emergency countermeasures for preventing from aggravating accidents, mitigating accidents and influence by radioactive material [1].

The objective of this paper is to analyze the small break loss of coolant accident (SBLOCA) with high pressure safety injection (HPSI) failure accident which is included in DEC. This study describes the safety analysis method and result considering the operator action for SBLOCA with HPSI failure accident in OPR1000 plant using SPACE (Safety and Performance Analysis Code for Nuclear Power Plant) [2].

## 2. Methods and Results

### *2.1 Scenario*

The initial event is a multiple failure that proceeds to a more serious condition by failing the safety injection system or recirculation operation after a small break loss of coolant accident as a design basis accident. In this case, the accident is assumed that the high pressure safety injection is failed at the beginning of this event after a LOCA in a cold leg is occurred.

The break occurs in the analysis and the coolant is released, but since the HPSI is not injected, the core water level is reduced to 70% within 400 seconds, exposing the top of the core heat structure. After the break, the core temperature was increased and then decreases similarly to the pressure behavior. The pressure of the pressurizer decreases sharply as the accident occurs. After about 500 seconds, the loop seal is generated in the middle loop. When the pressurizer pressure is 10.93 MPa, the low pressure safety injection (LPSI) injection starts at a small amount, and at 4.31 MPa, the safety injection tank (SIT) injection also starts. However, low levels of LPSI and SIT injection do not restore core water levels. As a result, the atmospheric dump valve (ADV) is opened in such a way as to cool the reactor cooling system quickly through the secondary side.

### *2.2 Accident Response Operation Strategy*

In the case of a small break loss of coolant accident with HPSI failure accident, the pressure of the reactor coolant system is maintained in a substantially high with the core uncovery if no proper accident response. Thus, the operator must open the steam generator ADV to reduce the pressure and temperature of the indirect reactor cooling system by increasing the heat transfer capacity. The opening of ADV flashes the water in secondary side and reduces the saturation temperature with the steam generator pressure drop. As a result, the pressure of reactor coolant system is lowered so that the injection of LPSI, which is injected in small quantities, becomes smooth, and a large amount of coolant can be supplied to the reactor core.

### *2.3 Results of Steady-state Condition*

Table 1 shows the results of the steady-state calculation using SPACE code (version 3.0) for OPR1000 nuclear power plant.

Table 1. The results of steady-state condition

| | Position | Calculation | Error (%) |
|---|---|---|---|
| Primary System | | | |
| Power (MWth) | 100% | 2815.0 | 0.0 |
| Pressure (MPa) | Pressurizer | 15.40 | 0.7 |
| Level (%) | Pressurizer | 52.61 | 0.0 |
| Temperature (K) | Hot leg | 602.11 | 0.3 |
| | Cold leg | 571.34 | 0.4 |
| Flowrate (kg/s) | Average channel | 14772.50 | 0.1 |
| | Hot channel | 82.77 | 1.3 |
| | Hot leg A | 7655.55 | 0.0 |
| | Hot leg B | 7652.70 | 0.0 |
| | Cold leg A1 | 3825.75 | 0.0 |
| | Cold leg A2 | 3825.78 | 0.0 |
| | Cold leg B1 | 3826.41 | 0.0 |
| | Cold leg B2 | 3826.41 | 0.0 |
| Secondary System | | | |
| Pressure (MPa) | Steam dome A | 7.38 | 0.0 |
| | Steam dome B | 7.39 | 0.1 |
| Level (%) | S/G A, NR-level | 42.98 | 2.3 |
| | S/G B, NR-level | 43.14 | 1.9 |
| Flowrate (kg/sec) | S/G A | 398.25 ×2 | 0.6 |
| | S/G B | 402.49 ×2 | 0.4 |
| | MFW A | 801.34 | 0.0 |
| | MFW B | 801.34 | 0.0 |

### *2.4 Results of Transient Condition*

We simulated a small break loss of coolant accident which is a break diameter of 0.0762m in the cold leg B2 loop with high pressure safety injection failure accident.

In this case, it is important to predict the steam temperature at the core exit due to the rise of the peak cladding temperature (PCT). The maximum temperature of the steam is about 345 °C. After the PCT, the pressure and temperature of the reactor cooling system drop sharply, and after about 500 seconds, a loop seal is generated in the middle leg, and the pressure slightly increases and then decreases again.

The low pressurizer pressure (LPP) signal occurs almost simultaneously with the PCT occurrence, and reactor trip, reactor coolant pump coastdown, main steam isolation, main feedwater isolation, and auxiliary feedwater injection begin. When the pressurizer pressure is 10.93 MPa and 4.31 MPa, the LPSI injection starts below 15 kg/s and the SIT flow rate is injected until the level drops to 20%. However, with a small amount of LPSI and SIT injection, the core water level is not restored and the water level is maintained at about 70%.

Therefore, if the heat of the reactor cooling system is removed to the secondary side after the steam generator atmospheric release valve is opened, the water level is restored quickly when the pressure and temperature drop sharply and when the pressure drops to about 2 MPa, the supply of LPSI becomes smooth.

### *2.5 Sensitivity Study for ADV Open Time*

Sensitivity calculations for the operator action time of 15, 30, and 60 minutes were performed to identify when it is appropriate.

Fig. 1 compares the pressurizer pressure with the steam generator ADV open delay time. The pressure in the reactor cooling system decreases sharply as soon as it break, then decreases slowly after a slight increase in pressure due to loop seal phenomena. At the same time as the ADV is opened, the pressure drops sharply. When the ADV is opened in 15 minutes, it reaches 4.31 MPa faster than the rest, and SIT injection starts first.

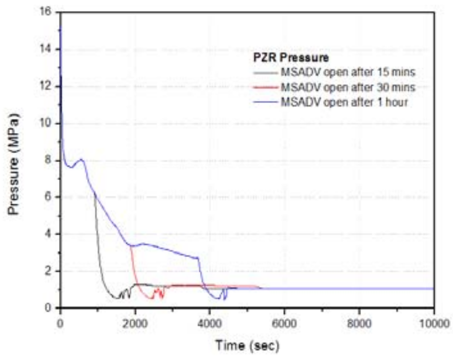


Fig. 1. Pressures of pressurizer

After 2,000 seconds, the pressure drops very slowly, so it takes a long time for the LPSI to be injected smoothly to about 2 MPa.

Fig. 2 shows the pressure of the steam generators. The pressure drops sharply to the opening of the ADV.

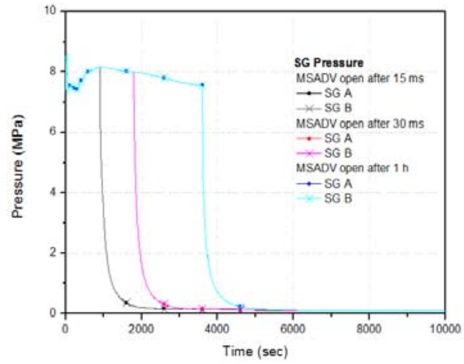


Fig. 2. Pressures of steam generators

Fig. 3 shows the LPSI mass flow rate and Fig. 4 shows the core water level. LPSI is initially introduced in small quantities and when the ADV is opened, the pressure drops rapidly to about 2 MPa, which causes the core water level to return immediately.

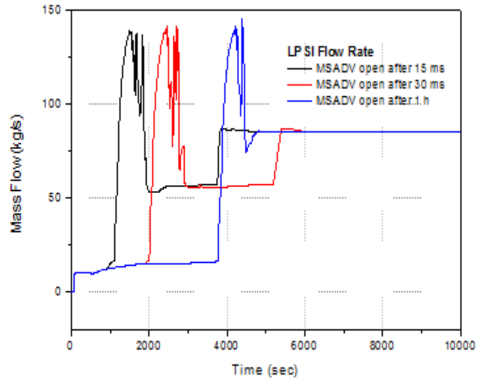


Fig. 3. Mass flow rate of LPSI

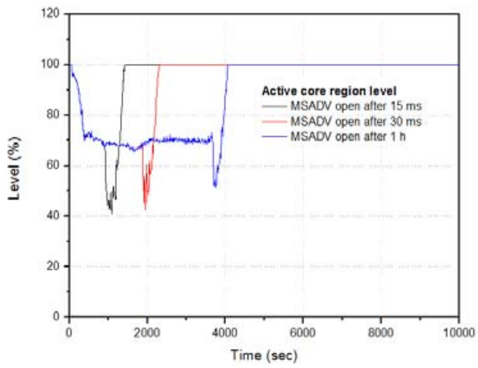


Fig. 4. Collapsed water level of active core

## 3. Conclusions

Recently, in order to simulate multiple failure accident with design extension conditions using the license and safety analysis code, we developed the SPACE input deck of the OPR1000 nuclear power plant and analyzed a small break loss of coolant accident with HPSI failure accident according to the strengthened domestic and foreign nuclear reactor regulatory requirements.

A preliminary analysis of SBLOCA with HPSI failure accident in OPR1000 was performed using the SPACE code to identify the core cooling capability and operator action time. In this study, it has been confirmed that an accident can be mitigated if the steam generator ADV opening time is fast. Opening the ADV allows the SIT injection to be accelerated, but due to the large amount of LPSI supply, SIT injection is relatively ineffective in core water level recovery. In order to restore the core water level, it is most effective to reduce the pressure of the pressurizer to 2 MPa or less and supply a large amount of LPSI.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] IAEA, SAFETY STANDARDS SERIES No. SSR-2/1, International Atomic Energy Agency VIENNA, 2012.
[2] SPACE 3.0 User's Manual, KHNP, 2017.