Preliminary analysis of SBLOCA Test for SMART-ITL using the SPACE Code

Yongjae Lee [a], Hwang Bae[a], Jong-Hyuk Lee [a*]
[a]*Korea Atomic Energy Research Institute, 111 Daedeokdaero 989Beon-Gil, Yuseong, Daejeon, 34057, Korea*

***Keywords :** SPACE, SMART-ITL, Safety analysis, SBLOCA

1. Introduction

As global interest in addressing the surge in energy demand grows, small modular reactors (SMRs) are being proposed as an alternative. Consequently, numerous SMR designs both domestically and internationally are undergoing licensing reviews and research and development. In Korea, the innovative-small modular reactor (i-SMR) is developed by the Innovative Small Modular Reactor Development Agency and proceeding with the application for standard design approval.

The i-SMR is a 170 MWe pressurized water reactor-based small modular reactor. It adopts an integrated design where the primary coolant system's main components are placed inside the reactor vessel, eliminating primary coolant piping and fundamentally preventing the possibility of a Large Break Loss of Coolant Accident (LBLOCA). i-SMR innovative design includes an internal control rod drive mechanism, helical type steam generators, boron-free reactor core, a Passive Auxiliary Feedwater System (PAFS), Passive Containment Cooling System (PCCS), and Passive Emergency Core Cooling System (PECCS).

The SPACE code is a thermal-hydraulic analysis code for safety analysis of pressurized water reactor [1]. The SPACE code was developed and improved with component models for the safety analysis of the i-SMR. These component models were validated using the various separate effect tests (SETs) and validation through integral effect tests (IETs) is further required to fully demonstrate the code's capability in predicting the integrated thermal-hydraulic behavior of the i-SMR. As IET for the i-SMR is under construction, SMART-ITL (IET for SMART) data was utilized to perform the code validation.

This study provides a comprehensive evaluation of the applicability of the SPACE code for simulating thermal-hydraulic phenomena in integral-type reactor systems, with particular emphasis on its capability to analyze system-level behavior and predict transient responses.

2. Methods and Results

2.1 SMART-ITL

The SMART-ITL test facility is a high-temperature, high-pressure experimental setup that provides a scaled-down simulation of key systems, including the reactor coolant system, of the SMART reactor developed by the Korea Atomic Energy Research Institute. It is designed, manufactured, and installed based on the reference SMART reactor, applying an appropriate scaled-down simulation design methodology. The general design criteria are as follows.

- Reference Reactor: SMART
- Height Ratio: 1/1
- Diameter Ratio: 1/7 (Volume Ratio: 1/49)

SMART-ITL simulates Small Break Loss of Coolant Accidents (SBLOCA), Design Basis Accidents (DBA), Beyond Design Basis Accident (BDBA). the Safety Injection System (SIS), the Data Acquisition System (DAS) for monitoring system operating variables and collecting data, and auxiliary systems supplying electricity, air, cooling water, etc., to the system.

The main equipment of the SMART-ITL test facility and the schematic diagram of the reactor coolant system are shown in Figure 1 [2]. The reactor coolant system generates heat using electric heaters and transfers this heat to the secondary system via helical type steam generators. The flow rate of the reactor coolant system is maintained constant using four reactor coolant pumps, and pressure is maintained via the pressurizer. The PRHRS is connected to each of the four secondary system loops. Following an accident, when the feedwater isolation valve and main steam isolation valve close, the isolation valves of the PRHRS open to remove residual heat from the reactor coolant system.

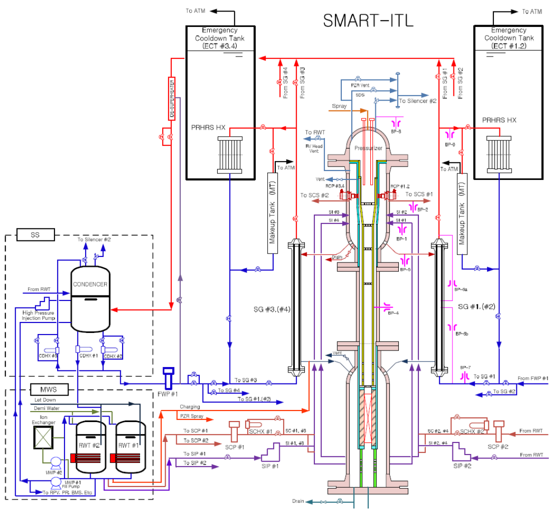

Fig. 1. Schematic diagram of the SMART-ITL facility

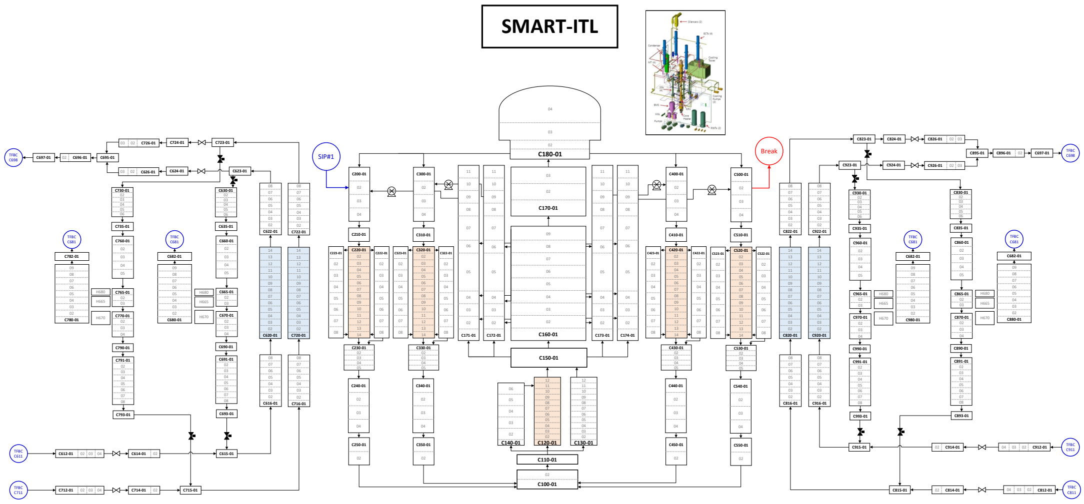

Fig. 2. SMART-ITL SPACE Nodalization

2.2 Analysis Results

Prior to performing the transient analysis for the SB-SIS-03 test, a steady-state calculation was conducted using the SPACE code. The measured values from the steady-state of the test and the results of the steady-state analysis are described in Table 1 and the nodalization of SMART-ITL is in Figure 2.

Table I: Initial Conditions of SB-SIS-03 test

Parameter (Unit)	SB-SIS-03	SPACE
Core power (MW)	1.451	1.451
PZR pressure (MPa)	14.94	14.94
PZR level (m)	3.02	3.02
Core inlet/outlet temperature (℃)	291.34/ 320.22	291.30/ 320.34
RCS flows (kg/s)	8.06	8.77
Feedwater/Main steam temperature (℃)	206.04/ 305.66	205.99/ 317.83
Feedwater/Main steam pressure (MPa)	5.46/ 5.43	5.45/ 5.43
Feedwater Flow (kg/s)	0.6374	0.6259

The initial event in the SB-SIS-03 test is the double-ended guillotine break of the safety injection piping. When the accident occurs and pressure decreases due to break flow, causing the reactor coolant system pressure to reach the low pressurizer pressure (LPP) setpoint, a reactor shutdown signal is generated after a 1.1 second delay time. Assuming turbine shutdown and loss of off-site power occur due to the reactor shutdown signal, feedwater pump stops and the reactor coolant pumps begin coastdown. 2.34 seconds after LPP occurs, a PRHRS operation signal is generated due to low feedwater flow. When the PRHRS activation signal occurs, the turbine is isolated by closing the feedwater isolation valve and the main steam isolation valve. The PRHRS operates by opening the inlet and outlet isolation valves of the PRHRS. The safety injection activation signal is generated when the reactor coolant system pressure reaches the set value and safety injection water is injected 30.0 seconds later.

The pressure behavior of the pressurizer is shown in Figure 3. The pressurizer pressure begins to decrease immediately due to the break flow, reaching the reactor shutdown setpoint (LPP). As shown in Figure 4, the calculated break mass flow rate during the early accident phase is higher than the experimental value, causing the reactor shutdown point to occur earlier than in the test. This discrepancy results from the conservative critical flow model used in the SPACE LOCA methodology. After reactor shutdown, the core power decreases sharply as shown in Figure 5 and is maintained according to the decay heat curve. After reactor shutdown, the pressurizer pressure continues to decrease due to break flow and residual heat removal system cooling, reaching the safety injection system activation setpoint. Safety injection begins after reaching the safety injection system activation setpoint, as shown in Figure 6. As the pressure in the reactor coolant system decreases to the pressure corresponding to the saturation temperature due to break flow, the temperature of the reactor coolant system gradually decreases to the saturation temperature, as shown in Figure 7.

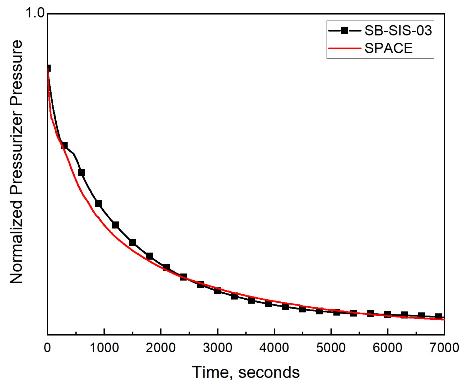

Fig. 3. Time vs. Pressurizer pressure

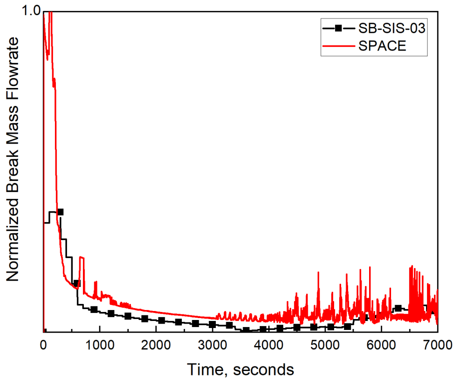

Fig.4. Time vs. Break mass flowrate

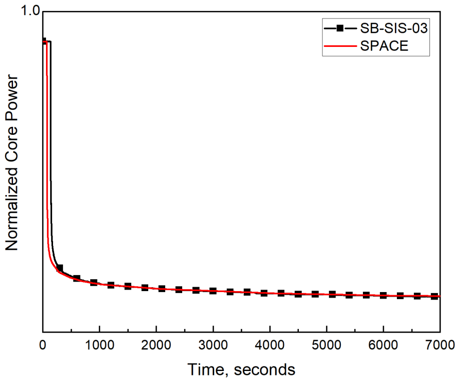

Fig. 5. Time vs. Core power

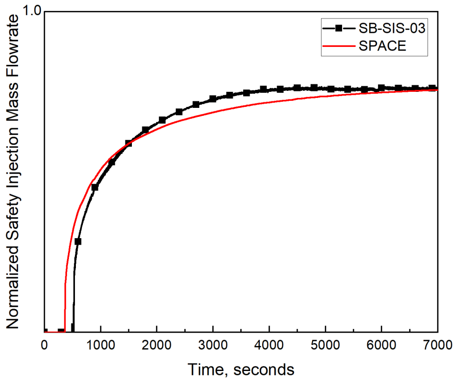

Fig. 6. Time vs. Safety injection mass flowrate

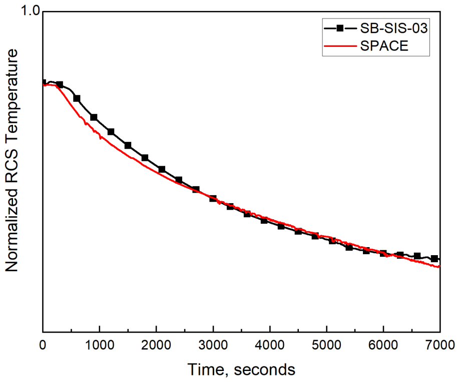

Fig. 7. Time vs. RCS Temperature

3. Conclusions

In this study, the reliability of the SPACE code was evaluated through validation against the SMART-ITL integral effect test. Although the break flow rate calculated by the SPACE code was overpredicted in the early stage of the accident due to the conservative critical flow model in the LOCA methodology, other thermal-hydraulic variables showed good agreement with the experimental measurements of the reactor coolant system. In conclusion, the SPACE code is confirmed to be applicable for the transient analysis of the integrated small modular reactors with helical steam generators.

ACKNOWLEDGMENTS

This work was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korea Government(MSIT) (No. RS-2024-00403548).

REFERENCES

[1] Sang Jun Ha, Chan Eok Park, Kyung Doo, Kim, and Chang Hwan Ban, Development of the SPACE code for nuclear power plants, Nuclear Engineering and Technology, Vol.43, p. 45-62, 2011.
[2] Hwang Bae, Dong Eok Kim, Sung Uk Ryu, Yong-Cheol Shin, Yung-Joo Ko, Sung-Jae Yi, Hyun-Sik Park, Yeon-Sik Cho, Jae-Seung Suh, An SBLOCA test of safety injection line break with the SMART-ITL facility and its MARS-KS code simulation, ICAPP 2014, 2014.