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SPACE Analysis of loss of SI injection concurrent with SBLOCA for SMART-ITL

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1. Introduction

The Phenomena Identification and Ranking Table (PIRT) for SMART100-DECs [1] has been developed to identify the thermal-hydraulic phenomena that could happen during the DECs without core melting of SMART100. Based on the PIRT, we also derive the improvement or validation items for thermal-hydraulic model of the SPACE. It is required to evaluate the capability of the SPACE including the new design features of SMART100 by adopting inherent and passive safety system. In this regard, thermal-hydraulic models of the SPACE has been improved to simulate the behavior of Passive Safety Injection System (PSIS).

To simulate thermal-hydraulic phenomena of SMART applications, an Integral Test Loop for the SMART design (SMART-ITL [2]) was constructed and various kind of validation tests on SMART were conducted. Only these test data were able to be available for validating the newly improved model. Among the accident scenarios of SMART-ITL, the F102 test for small break loss of coolant accident (SBLOCA) concurrent with partially safety injection fail was selected to validate the capability of the SPACE for SMART application in this study. The study aims at evaluating the capability of the SPACE for SMART application by validating the SBLOCA scenario of SMART-ITL.

2. Methods and Results

2.1 Scenario (SBLOCA concurrent with SI fail)

SBLOCA initiates by the break at the Safety Injection (SI) line. Upon the break initiation, the Reactor Coolant System (RCS) pressure begins to decrease and a reactor trip signal is generated when the pressurizer (PZR) pressure reaches the low PZR pressure (LPP) set-point. As the turbine trip and loss of offsite power (LOOP) are assumed to occur simultaneously with the reactor trip. Reactor Coolant Pumps (RCPs) start to coast-down. Feedwater Injection Valves (FIVs) and Main Steam Isolation Valves (MSIVs) were closed simultaneously. Although Core Makeup Tank Actuation Signal (CMTAS) and Passive Residual Heat Removal Actuation Signal (PRHRAS) were generated by LPP, all the CMTs of PSIS and PRHRS are assumed to be failed in this scenario. An isolation valves of Safety Injection Tank are opened when the PZR pressure reaches the Safety Injection Tank Actuation Signal (SITAS) setpoint.

Table I Sequence of Events in SBLOCA (F102) [3]

Event	Setpoint	Time (s)
Initiation of Break	-	0
Generation of RCS trip signal - Turbine trip - RCP coastdown - FW stop - CMTAS	LPP+1.1 s	701
Control Rod Injection	LPP+1.6 s	702
PRHRAS	LPP+5.2 s	
MSIV / FIV close	PRHRAS+5.0 s	710
SITAS	P_{PZR} =2 MPa+1.1 s	5,658
SIT injection	SITAS+1.1 s	5,661
Test Ended		241,662

Table I shows major sequence of event of the SBLOCA scenario for SMART-ITL test.

2.2 Steady State Condition

The SMART-ITL facility is modeled as a single RPV and four SG components. These components are enveloped by the solid walls with heat losses through the surroundings. The surrounding ambient temperature is assumed as 303.15 K.

The adiabatic passive safety injection system (PSIS) lines including CMTs and SITs are connected at upper downcomer of the RPV and MS lines are connected to the top of SG. The upper and lower annulus volumes in the RPV are modeled by using the single PIPE component with annulus option. While the SMART plant is an integral reactor and SGs are encapsulated in the RPV vessel, SMART-ITL is designed that the SGs are installed in exterior of the RPV and connected with pipe lines. The FW line connected to the SG inlet is also modeled and the feed water is supplied by TFBC component using flow boundary condition at constant flow rate.

The core heater power is set to 1,711 kW. In addition to the core heater power, PZR heaters are also working in the steady state conditioning phase. The PZR heater power is set to 30.0 kW.

Total 4 RCPs are running with adjusted total 11.525 kg/s and the flow rates are evenly divided to each SG. The adjusted mass flow rate is come from the heat balance concept of steam generator. Once the pump trip is on, the pump coast down in 5.0 second, as is the experiment pump run data. Table II summarizes the steady calculation result of important parameters and percentage deviations from the experiment.

Table II Steady Calculation Results of SBLOCA(F102)

	EXP	SPACE	Diff(%)
Initial Core Power (kW)	1,711	1,711	BC
Core inlet & Outlet (K)	568.55	568.30	-0.043
	594.75	594.17	-0.098
SG primary Inlet & Outlet (K)	594.95	593.96	-0.166
	571.45	570.00	-0.253
RCS flow rate (kg/s)	11.525	11.52	adjusted
Pressure (MPa)	15	15	BC
PZR temp (K)	613.15	615.25	0.342
PZR water level (m)	3.115	3.074	-1.316
SG secondary Inlet & Outlet (K)	502.85	502.86	BC
	590.15	593.93	0.639
SG flow rate (kg/s)	0.784	0.784	BC
FW Pressure (MPa)	5.72	5.72	BC
MS Pressure (MPa)	5.63	5.69	1.066

2.3 Transient Results

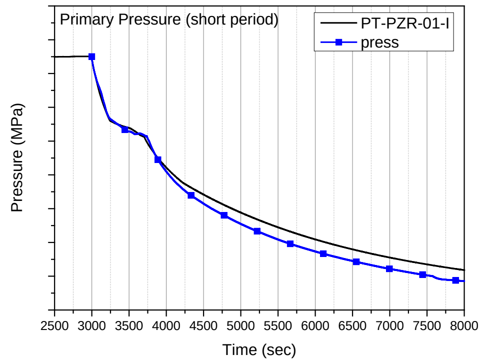
The break boundary is connected to the upper RPV annulus volume located at the down-stream position of the pump. Ransom-Trapp critical flow model is applied to the break face with the all phasic discharge coefficients are 1.0. The break valve opens at 3,000 second in the SPACE calculation.

Fig. 1 shows the comparison of primary pressure between the SPACE calculation and F102 test data. Upon the break initiation, primary pressure was rapidly decreased to the LPP setpoint. As the RCS pressure reached to the setpoint, the reactor trip signal was generated, and core power started to decrease.

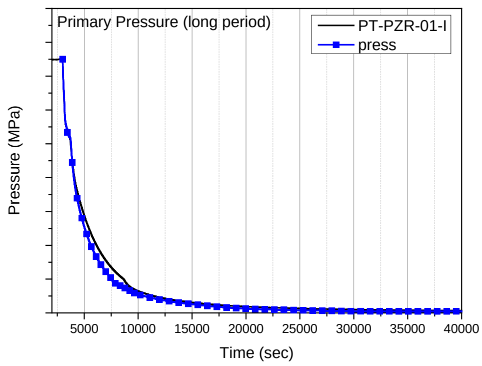
Fig. 2 shows the comparison of accumulated mass of break flow between the SPACE calculation and the test data. The SPACE prediction shows larger break flow than the test for the whole period. Because of this, the RCS pressure in the SPACE prediction is more rapidly decreased when comparing with the test as shown in Fig. 1. For test data after 8,000 second, the accumulated mass is zero due to the discharge of the reserve tank at that time.

In this scenario, SIT only involved to mitigate the SBLOCA. The pressure of SIT is shown in Fig. 3. The pressure peak in SIT appears earlier than test because the primary pressure earlier reached to SIT setpoint in the SPACE calculation. However, the behavior of pressure in the SIT is well predicted including the effect of non-condensable gas in the tank. The comparisons of SIT injection between the SPACE prediction and test data are shown in Fig. 4. The predicted injection flow rate show a good agreement with test data.

Fig. 5 shows the comparison of RPV water level. The SPACE predicts the lower RPV water level due to the excessive break flow. As a further work, sensitivity study will be conducted for the critical flow model for break simulation.



(a) Short period



(b) Long period

Fig.1 Primary pressure of SBLOCA(F102)

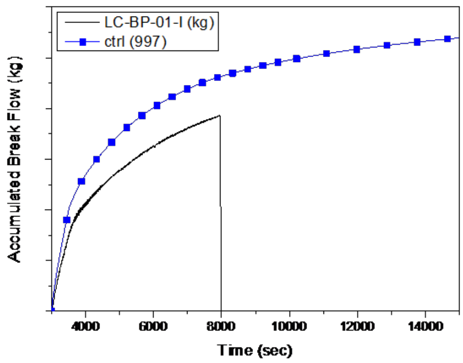


Fig.2 Integrated mass of break flow

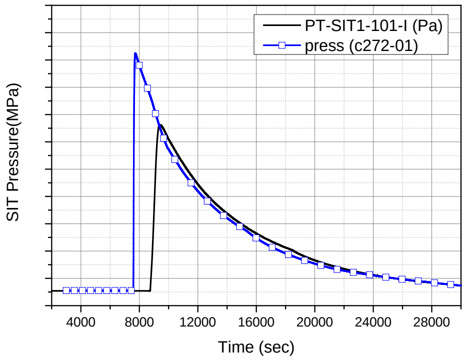


Fig. 3 SIT Pressure behavior

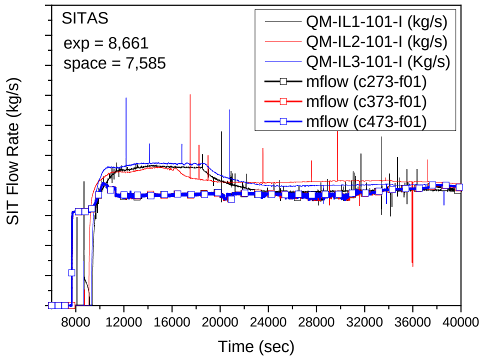


Fig. 4 SIT flow rate

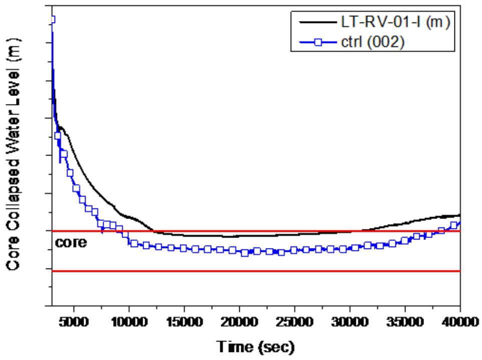


Fig. 5 RPV water level

3. Conclusions

The special component model for SMART in the SPACE has been developed to evaluate the capability of the SPACE for SMART100-DECs. To validate the newly improved T-H models of the SPACE, the SBLOCA (F102) scenario of SMART-ITL was simulated. The SPACE calculation for major parameters show reasonable agreements with the test. Based on these, the special component model for SMART is well-implemented and we can prove that the SPACE can be utilized for SMART applications

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