MARS-KS Assessment for ROSA/LSTF Test 3-1

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1. Introduction

This paper documents the results of evaluation analysis by using the MARS-KS code for test Large Scale Test Facility (LSTF) 3-1 "SB-LOCA without Scram" of which the break size is equivalent to 2.8" in the actual plant. The LSTF facility [1] represents a typical Westinghouse plant of four-loop 3423 MWt pressurized water reactor (PWR). The LSTF is characterized by the use of prototypical-scaled components with full-height, 1/48 volume and full-pressure conditions to the reference PWR. Currently, the LSTF is used for the Rig of Safety Assessment No.5 (ROSA-V) program.

2. Overview of Test 3-1 Experiment

The LSTF Test 3-1 [2] is an experimental simulation of the PWR high-power natural circulation due to failure of scram during cold leg small break loss-of-coolant accident (SB-LOCA) with a break size of 1% under an assumption of total failure of high pressure injection system. In the experiment, the primary loop two-phase natural circulation continued until about 300 s when steam generator (SG) relief valve terminated continuous opening. Liquid accumulation in the SG upflow-side (hot side) U-tubes and inlet plenum took place during reflux condensation mode probably because of counter-current flow limiting (CCFL) at the inlet of the U-tubes and the bottom of the inlet plenum due to high vapor velocity by high core power. Flow in hot legs became supercritical (Fr > 1) during two-phase natural circulation due to high vapor and liquid velocity, causing the hot leg liquid level quite low. The LSTF core protection system automatically decreased the core power down to 25 % of the decay power level as the maximum fuel rod surface temperature reached 903 K at about 1820 s. Vapor condensation on coolant injected from accumulator tanks into cold legs induced loop seal clearing only in the loop without pressurizer (PRZ) which enhanced the core uncover followed by steep reflooding with a sudden core quench.

3. MARS-KS Assessment

3.1 Steady State Analysis

The base input deck for the test 3-1 was based on the RELAP5 input deck which was given by the LSTF test team but some modifications were added to the original deck. Multi-dimensional component for the reactor pressure vessel (PRV) including core, downcomer, lower plenum, upper plenum and upper head region was introduced to simulate an asymmetric behavior during transient. As shown in Table I, the core power profile was modified to be fitted to the multi-dimensional core and to simulate appropriate power shape (Case 3) with the axial peaking factor of 1.495 in this test.

From the steady state analysis, appropriated results were achieved as shown in Table II.

Table I: Multi-dimensional Core Power Distribution

Sector \ Ring	Inner		Middle		Outer	
	N	Q (W)	N	Q (W)	N	Q (W)
1	28.5	288.9	75.9	992.6	64.4	411.6
2	28.5	288.9	75.9	992.6	64.4	411.6
3	28.5	279.4	77.1	948.0	60.8	388.8
4	28.5	288.9	75.9	992.6	64.4	411.6
5	28.5	288.9	75.9	992.6	64.4	411.6
6	28.5	279.4	77.1	948.0	60.8	388.8
Total	171	1,714.4	457.8	5,866.4	379.2	2,424.0

N: number of heated rods

Table II: Comparison of Steady State Results

Parameters	Experiment (w/wo PZR)	Simulation (w/wo PZR)
Core Power (MW)	10.10	10.10
Hot-leg fluid temp. (K)	598.2/597.9	600.4/600.5
Cold-leg fluid temp. (K)	563.2/563.0	563.9/563.9
Loop mass flow rate (kg/s)	24.63/24.33	24.3/24.0
PRZ Pressure (MPa)	15.52	15.50
PRZ Level (m)	7.28	7.36
SG pressure (MPa)	7.31/7.32	7.30/7.30
SG level (m)	5.5/5.48	5.22/5.54
Steam flow rate (kg/s)	2.67/2.60	2.85/2.80

3.2 Transient Analysis

In a transient analysis, the core protection system was not implemented. Instead, exactly the same decay power curve as in the experiment was used. A similar approach was adopted for the pump coastdown simulation.

The transient simulation was initiated by opening the break valve at the cold leg in the primary loop without the PRZ. The inner diameter of the break valve is 10.1 mm and Henry-Fauske critical model was applied to it. The discharge coefficient and non-equilibrium factor are adjusted to 0.85 and 0.07, respectively.

Fig. 1 shows a break flow rate and an integrated break flow. As for the maximum break flow, the simulated value (7.5 kg/s) is lower than experimental value (9.4 kg/s) but the overall trend shows a good agreement with an experiment before the accumulator injection. After accumulator injection, the break flow rate is strongly affected by the accumulator flow and the integrated break flow in the simulation is also larger than experimental data.

As shown in Fig. 2, the primary and the SG pressure in the simulation are in accord with those of experiment except after the accumulator injection. During a accumulator injection, the primary pressure decreases lower than the experimental data and as a result, the accumulator injection in the simulation is much greater.

Fig. 3 shows the core levels. It shows similar trend to the experimental data but as explained above, after accumulator injection, deviation from the experimental data becomes larger.

As shown in Fig. 4, supercritical flow (Fr > 1) in the hot leg, which is one of the most important phenomena of this experiment, occurs at high power period (< 300 s), but its magnitude is less than the experimental data. This means that the simulated liquid velocity in the hot leg is smaller than the experimental data.

4. Conclusions

For the purpose of the assessment of the MARS-KS code, we performed the simulation for the LSTF test 3-1 experiment. From the results, overall trends of major parameters such as the pressure and the break flow rate showed a good agreement with the experimental data. Moreover, the MARS-KS predicted a supercritical flow in the hot legs during a transient even though its magnitude was smaller than that in the experiment. However, there were big discrepancies in the water levels, i.e., the core, upper plenum, hot legs and cold legs. These deviations might result from the wrong input data which was derived from the original RELAP5 input. Therefore, more investigations on the input data such as form loss factor and junction options should be required.

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[2] Thermo-hydraulic Safety Research Group, Quick-look Data Report of ROSA/LSTF Test 3-1 (High Power Natural Circulation Experiment SB-CL-38 in JAEA), JAEA, 2007.

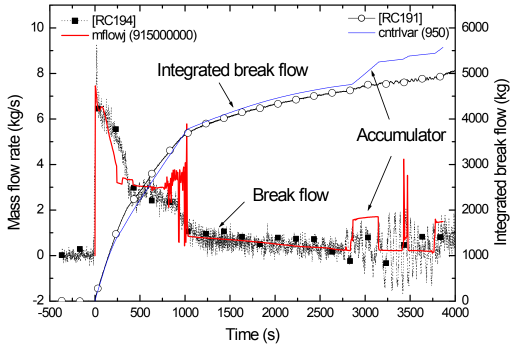

Fig. 1. PRZ and SG pressure

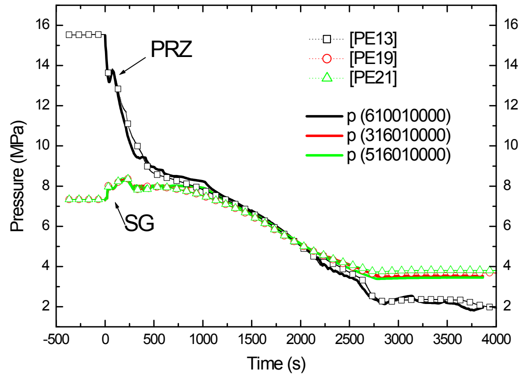

Fig. 2. PRZ and SG pressure

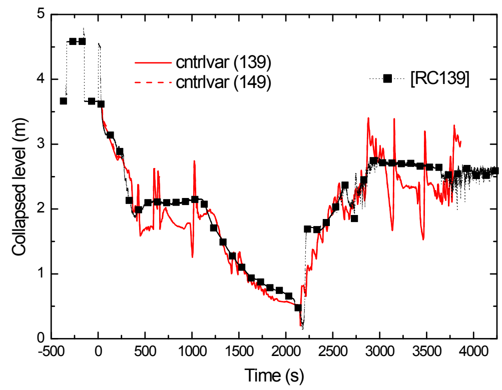

Fig. 3. Core water level

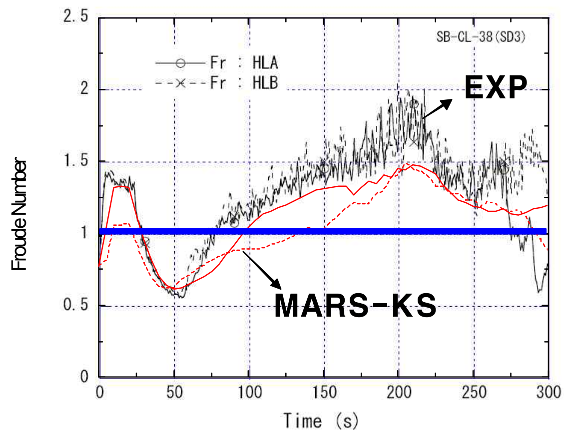

Fig. 4. Froude number (supercritical flow)