Post-Test Analysis of PKL G3.1 Test using MARS-KS

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1. Introduction

The large-scale test facility PKL is a scaled-down model of a 4-loop pressurized water reactor (PWR) of the 1300 MWe class. The PKL test facility models the entire primary system and essential parts of the secondary system without a turbine and condenser. Though all elevations are scaled 1:1, volumes, power and mass flows are modeled by a scaling factor of 1/145. The maximum power of 2.5 MW corresponds to 10 % of the rated thermal power in commercial plants. The maximum pressure of the primary system is 45 bars.

In this study, the PKL III G3.1 test, which was conducted with the OECD/NEA-PKL2 project, was simulated by the MARS-KS code [1] as part of a post-test calculation, which follows the pre-test analysis performed in the earlier study [2].

2. Description of PKL III Test G3.1

The objective of the PKL III G3.1 test is the investigation of the fast cool-down transient by a main steam line break (MSLB) at the upstream of the main steam isolation valve (MSIV) during the hot stand-by condition (reactor shut down). Once the MSLB occurs, both pressure and temperature in the affected steam generator (S/G) sharply decrease due to the boil-off phenomena and heat transfer from the primary side to the secondary side increases drastically. As a result, the core power returns to its recritical state by a negative temperature coefficient due to a fast cool-down transient.

The test procedure of the PKL III G3.1 is divided into two phases. Phase 1 is the fast cool-down phase by the MSLB, and Phase 2 is the high-pressure safety injection (HPSI) phase through the cold legs in loop 1 and 4. The initial conditions for the PKL III G3.1 test are summarized in Table 1[3].

Table 1. General boundary conditions of the PKL III G3.1 test

Parameters	Value
Total heater power (kW)	260 (compensating heat loss)
Primary Pressure (bar)	42
Core exit temperature (°C)	246 (~10 K subcooled)
Loop flow rate (kg/s)	34
PRZ level (m)	7.4
SG pressure	35
SG collapsed level (m)	9.2 (affected) / 12.2 (intact)
SG downcomer temperature (°C)	200 ~ 210 (affected) 240 (intact)

At the start of Phase 1, all S/Gs are isolated from the feedwater system and all MSIVs remain closed. The test begins with the opening of the break valve located at the front side of the MSIV in the S/G 1. The diameter of the break orifice is set to 29 mm. The main coolant pumps (MCP) are also tripped, coastdown begins at the same time. Each butterfly valve located at the inlet of the MCP is closed at 210 s. Until the affected S/G becomes empty, the primary pressure and temperature as well as those of the secondary side in the affected loop continuously decrease. After the dry-out of the affected S/G, the primary pressure and temperature increase.

Phase 2 begins with the HPSI through two cold legs in loop 1 and 4 at 1030 s from the start of the test (SOT). The initial mass flow rate of the HPSI is 0.2 kg/s per loop, but the flow rate is reduced to 0.14 kg/s per loop after 2150 s from the SOT. After the HPSI injection, the pressurizer (PRZ) water level and pressure rapidly recover to the initial values. Finally, the PRZ water level reaches the full level, and the PRZ pressure is controlled nearby 42 bars via the pressurizer relief valve. The opening and closing setpoints of the valve are roughly set to 42 bar and 39 bar, respectively.

3. Post-Test Analysis

3.1 Preparing Code Input and Setup Initial Conditions

The MARS-KS input for this assessment is based on the input already used for the earlier study[2] with some modifications. These modifications are as follows.

- Butterfly valve model → increasing form loss factor (after 210 s)
- Decreasing break orifice form loss coefficient
- Changing PRZ safety valve open/close rate
- Increasing form loss of MSL break valve
- Increasing discharge coefficient of break orifice

The initial conditions for the PKL III G3.1 test are not the exact steady state but quasi-steady state, so that S/G pressure and the primary coolant temperature slowly increase at the rate of 12 K/h [3] because there is no heat removal via the S/Gs. Therefore, we have simulated a quasi-steady state at an interval of 100 s for 400 s and selected proper conditions among them. Table 2 is the list of selected conditions, and it shows good agreement with the desired condition.

Table 2. Comparison of desired and calculated data

Parameters	Desired	Cal.	Err(%)
Core power (kW)	260	260	Const.
Primary pressure (bar)	42	42*	0.0
Core exit temperature (°C)	246	244	-0.8
Loop flow rate (kg/s)	34	34	0.0
PRZ level (m)	7.4	7.36	-0.4
S/G pressure	35.0	35.1	+0.3
S/G collapsed level (m)			

- Affected	9.2	9.27	+0.8
- Intact	12.3	12.43	+1.1

* Pressure is controlled via heater power of 12 kW

3.2 Post-Test Analysis using MARS-KS

The post-test analysis of the G3.1 test begins with the opening of the break valve located at the connecting pipe between main steam line of the S/G 1 and separator vessel to accumulate the break flow.

We performed post-test analysis for two cases. The first one is 'Base' case (Case-0) which has no modification of the SG riser volume. The second one is 'Case-1' which has increased the SG-1 riser volume by 10 % for prolonging the empty time of the affected SG. Fig. 1 shows behaviors of the break flow rate and cumulated break flow. The affected SG of Case-0 becomes empty faster compared with experiment data. In Case-1, however, we can find out that the empty time is extended as expected. Moreover, the accumulated break flow in Case-1 corresponds better to the experimental data when compared with Case-0.

The upstream and downstream pressures of the break orifice are almost same as the experimental data as shown in Fig. 2. We can also find out that there are little differences between Case-0 and Case-1 for the pressure behavior during most of transient period.

Fig. 3 shows the comparison of the RCS flow rate and temperature difference between the inlet and outlet of the affected SG. During steam blowdown phase, RCS flow rate and temperature difference in the affected loop show good agreements with experimental data. Also, it is found out that after the shutoff of the butterfly valve, the RCS flow rate sharply decreases due to a large hydraulic resistance. However, the temperature difference decreases very rapidly as loop-1 RCS flow rate decreases compared with experimental data. Therefore, it can be said that the temperature difference after the end of blowdown strongly depends on the RCS flow rate because heat transfer rate between primary and secondary side is enhanced as the RCS flow rate increases during this period.

4. Conclusions

From the post-test analysis by using the MARS code, we can find out that overall trends of the major parameters agree well with experimental data, especially, until the dryout of the affected SG. As for the case study, the calculation results of Case-1 show better agreement with the experimental data than those of base case. However, even though not explained in this paper, the RPV inlet temperature shows a big discrepancy compared with the experimental data, which may result from the different heat loss and the MCP cooling in the primary loops. In addition, minimum PRZ pressure of MARS is much higher than that of the experiment due to the existence of vapor in the PRZ surge.

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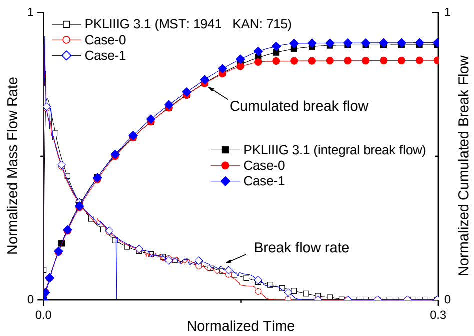

Figure 1. Break flow rate and mass

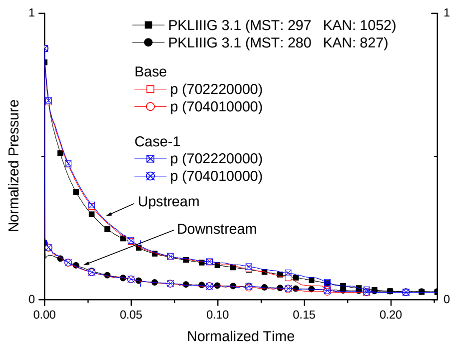

Figure 2. Upstrean and downstream pressure of break orifice

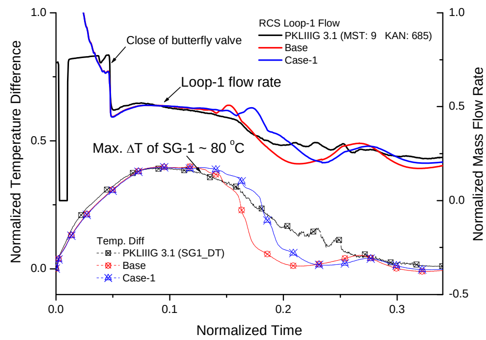

Figure 3. RCS flow rate and ΔT of SG in affected loop