Pre-Test Calculation of PKL III G3.1 Test

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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 modelled 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 was simulated by the MARS-KS code [1] as part of a pre-test calculation where no comparative experimental data is provided except for the boundary and initial test conditions. 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).

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.

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 66 mm. The main coolant pumps (MCP) are also tripped, and coastdown begins at the same time. Until the affected S/G becomes empty, the primary pressure and temperature as well as those of the secondary side continuously decrease. After the dry-out of the affected S/G, the primary pressure and temperature increase again.

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 43 bar and 41 bar, respectively.

3. Pre-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 PKL III F1.1 test assessment [2] with some modifications. The RPV downcomer is modelled as a 'multid' component to simulate asymmetric loop behaviours, and the other parts consist of one-dimensional components. Because the MSLB occurs in the running of the MCP, the pump data has been modified to simulate a constant pump velocity of 2500 rpm. The coastdown after the pump trip is also taken into account with a pump velocity data given by the test team.

The initial conditions for the PKL III G3.1 test are not the exact steady state but quasi-steady state which means that S/G pressure and the primary coolant temperature slowly increase at the rate of 12 K/h 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 1000 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 (K)	519	517	-0.4
Loop flow rate (kg/s)	34	34	0.0
PRZ level (m)	7.4	7.37	-0.4
S/G pressure	35	35.1	+0.3
S/G collapsed level (m)			
- Affected	9.2	9.1	-1.1
- Intact	12.3	12.4	+0.8
S/G downcomer temp. (K)			
- Affected	473~480	479	+0.5
- Intact	513	514	+0.2

* Pressure is controlled via heater power of 12 kW

3.2 Pre-Test Analysis using MARS-KS

The pre-test analysis of the G3.1 test begins with the opening of the break valve with the diameter of 29 mm, located at the main steam line of the S/G 1. Trap-Ransom choked flow model has been used for the break valve because the break flow is almost a single-phase vapor in this case, and several discharging coefficients, C_D, are used for the sensitivity study, 0.5 ~1.0.

Fig. 2 shows behaviors of the pressure and break flow rate in the affected S/G. The affected S/G pressure decreases drastically as soon as the break valve opens. The pressure decreasing rate and choked break-flow rate are proportional to C_D, as expected. The empty times of the affected S/G are 500 s, 690 s, 750 s, and 800 s for each case.

Fig. 3 shows the PRZ and affected S/G water level. From this figure, it is found that the affected S/G becomes empty faster as the C_D increases. The PRZ level also decreases until dryout of the affected S/G and then slowly increases because heat removal via S/G is no longer available. The increasing rate of the PRZ level is much larger after the HPSI flow is injected.

Fig. 4 shows the core outlet coolant temperature and affected S/G level. The core outlet temperature also decreases until the affected S/G becomes empty and then increases before the HPSI starts.

According to the information report for pre-test calculation [3], the measured core outlet temperature is about 498 K at SOT=1000 s. However, from the calculation results, the core outlet temperature is estimated at 499 K, and 496 K for C_D = 0.7 and 0.6, respectively at SOT=1000 s. From this result, it can be said that a proper discharging coefficient, C_D, may be in the range of 0.6 ~ 0.7.

4. Conclusions

A pre-test calculation for PKL III G3.1 fast cooldown transient test has been performed using the MARS-KS code. A fast cooldown due to the MSLB results in the overcooling of the primary side and an asymmetric loop temperature behavior. In addition, it is found that a proper discharging coefficient may be 0.6 ~ 0.7.

These pre-test calculation results will be revised and used as boundary conditions for the pre-test analysis of the ROCOM test, whose objective is to investigate the mixing phenomena of cold and hot water in the reactor pressure vessel downcomer and lower plenum.

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[3] Test PKL III G3.1 Information for pre-test calculation report, Mar, 2009.

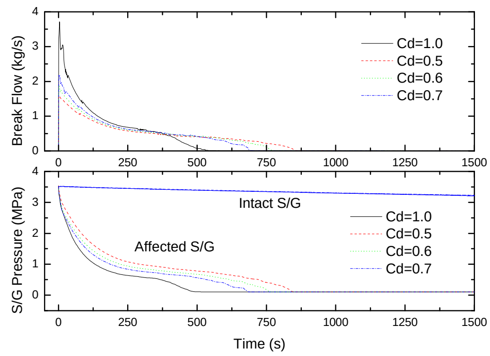

Figure 2. Break flow and S/G pressure

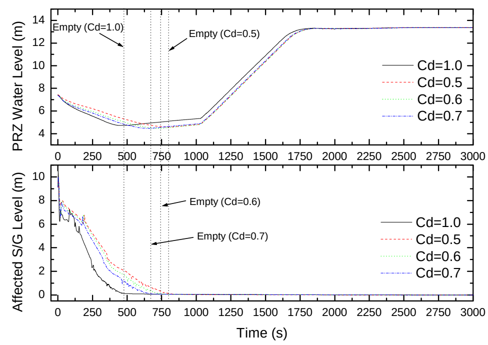

Figure 3. PRZ and affected S/G level

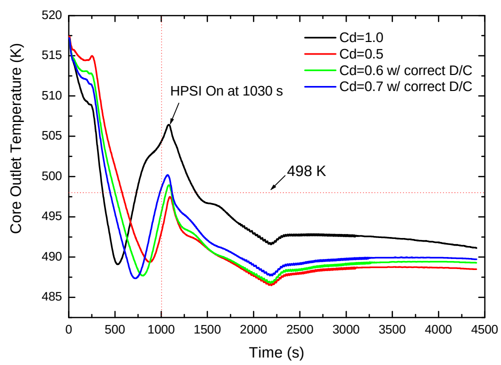

Figure 4. Coolant temperature at the core exit