Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Simulation of Station Black Out accident scenario (PKL H2.2) in PKL test facility

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1. Introduction

After the Fukushima accident, it is a safety issue to cope with the accidents with multiple failures, so called as DEC (Design extension condition). The interest in DEC accidents has led to the discussion on the extension of the scope of code use. It is required to validate the thermal-hydraulics phenomena with safety analysis code for the scope of extended accident.

Therefore, it is aimed to assess the predictability of SPACE code[1] for DEC accidents. The PKL H2.2 test [2] was selected to validate the capability of SPACE code among the DEC accidents. H2.2 test was conducted at PKL (**P**rimä**k**reis**l**auf, i.e. Primary-side circuit) facility, whose reference plant is the Philippsburg 2 nuclear power plant in Germany, as a part of the OECD-PKL3 project[3]. The target scenario of PKL H2.2 was Station Black Out (SBO) with failure of the entire power supply.

2. SPACE analysis on PKL H2.2 test

The PKL H2.2 scenario is SBO with total failure of the AC-power supply. This implies the failure of safety injection systems operating at high and low pressure and the operation and emergency steam generator (SG) feed-water supply. To prevent core meltdown, accident management was employed as follows:

- Secondary-side depressurization
- Primary-side depressurization through the safety and relief valves over the pressurizer (PRZ)
- Injection from accumulators (ACCs)
- The feed of the secondary-side by mobile pump or emergency feed-water system (EFWS) into 2 SGs

2.1 SPACE modeling

Fig 1 presents a nodalization diagram of SPACE for the PKL facility. It has 4 identical reactor coolant loops including SGs, cold-leg, reactor coolant pump, and hot-leg arranged symmetrically around the reactor pressure vessel. A PRZ-SV/RV (safety valve/relief valve), which is in charged on an important role in accident managements is modeled in the same way as the actual test.

The PKL H2.2 test is consists of a conditioning phase and an afterSoT (after start of test) phase. The conditioning phase includes setting up the initial test condition at hot stand-by condition. The steady-state was calculated following the procedure of PKL H2.2 test in the conditioning phase. The decay power in core was kept constant during the conditioning phase. The reactor coolant pumps were initially worked and stopped. Then the transition to natural circulation observed and approached to steady-state. To control the PRZ level, CVCS (chemical & volume control system) and PRZ heater was operated and the feed water is also controlled to keep a certain level of SGs. The calculated results, which is normalized by the valued of test represented in table 1, are utilized as an initial condition for the afterSoT phase. The SPACE modeling for PKL test facility was properly conducted and the results of initial conditions for the transient calculation have a good agreement with the test data.

2.2 Sensitivity study

It is important to determine the inventory loss through a PRZ-SV/RV in simulation of PKL H2.2 test. In this calculation, Ransom-Trapp choke flow model was used in the PRZ-SV/RV.

For a PRZ-SV, there is no discrepancy of discharged mass according to the variation of discharged coefficients because it is highly dependent upon the control logics, which control the open/close of valve with respect to the primary pressure.

When a top of reactor core is uncovered, a core exit temperature (CET) is sharply increased and PRZ-RV is opened as following the PKL H2.2 scenario, which will be discussed in more detail in next chapter. At that time, most of discharged flow is a vapor due to a low level of PRZ. The accumulated mass through PRZ-RV compared with SPACE results varying the discharged coefficient of vapor phase as shown in fig 2.

Table I: The results on the conditioning phase of PKL H2.2

Parameters	**Normalized values (SPACE/Test)**
Normal power (kWth)	0.99
Pressurizer pressure (bar)	0.99
Core Exit Temperature (K)	0.98
PRZ temperature (K)	1.01
PRZ fill level (m)	1.00
SG pressure (bar)	1.00
SG level (m)	0.93~0.98

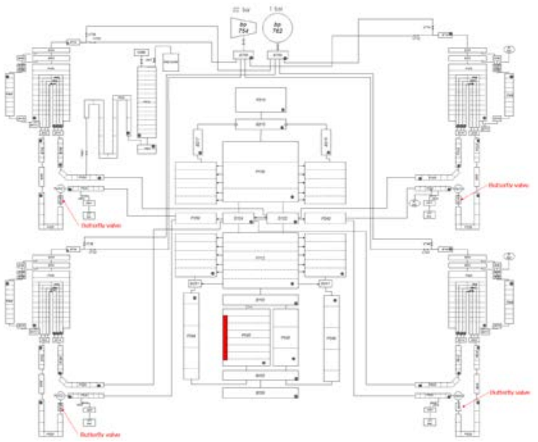

Fig 1. Nodalization of SPACE for PKL test facility

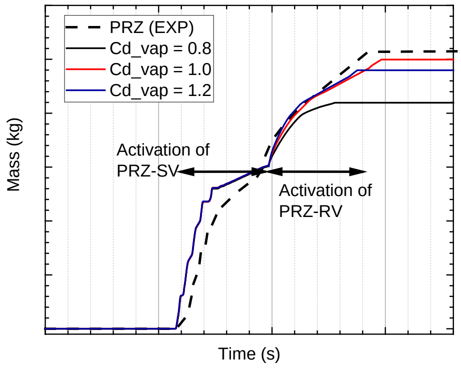

Fig 2. The results on discharge coefficient comparing the PKL H2.2 test data

2.3 SPACE analysis

The PKL H2.2 test procedure can be briefly summarized as below:

At the start of the test, the core power starts to decrease and the feed water system, CVCS, additional heater are switched off. Due to decayed core power, the primary pressure is initially decreased. However, the degradation of heat transfer in SGs is occurred because evaporation at secondary side of SG leads to the decrease in SG fill level. A CET was saturated and vapor was generated in reactor pressure vessel (RPV). The primary pressure developed and the coolant move into the PRZ, which cause a rapid increase of the PRZ level. The test criterion of PRZ level was reached to trigger secondary-side depressurization. However, primary pressure is continuously increased after that pressure control started via the PRZ-SV. Due to the loss of inventory via PRZ-SV, the core is uncovered and start to heat-up. When a CET reached to the response temperature, the PRZ-RV was totally opened to decrease the primary pressure (i.e. Primary-side depressurization). Since ACCs were injected into the cold legs by using the only pressure gradient, the increased temperature in core was cooled down. However, the CET increased after the depletion of ACCs. The test was terminated after the activation of EFWSs, whose feed water injected into the secondary side for 2 loops.

Based on the SPACE input obtained by the sensitivity stury, the SPACE simulation was conducted for PKL H2.2 test.

Fig 3 present the primary pressure behavior. The initial pressure behavior is well predicted but the time for opening of PRZ-RV in SPACE calculation is later than the test. Because it has a different tendency of a sudden rising of core exit temperature and a core liquid level between test and SPACE code as shown in fig 4.

The SGs fill level was also compared in fig 5. The calculated results have a good agreement with test data. However, the injection rate for EFWSs is a smaller comparing with the test. Because of this, the primary pressure and core fill level could not follow the test data at the end of the SBO scenario. Based on these results, we can conclude that it is required to improve the modeling for the injection of EFWSs.

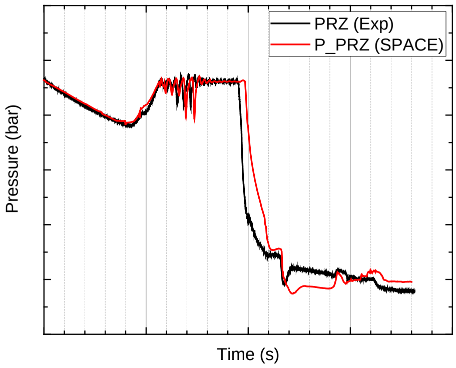

Fig 3. Comparison of primary pressure behavior between PKL H2.2 test data and SPACE calculation

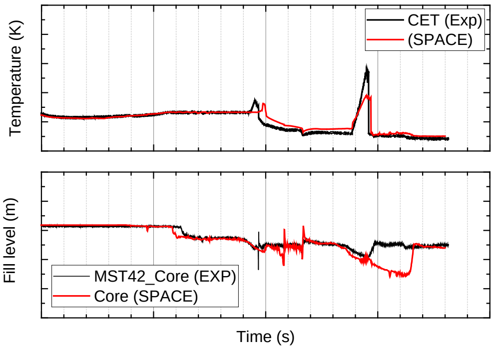

Fig 4. Comparison the CET (upper) and core fill level (lower) between PKL H2.2 test data and SPACE calculation.

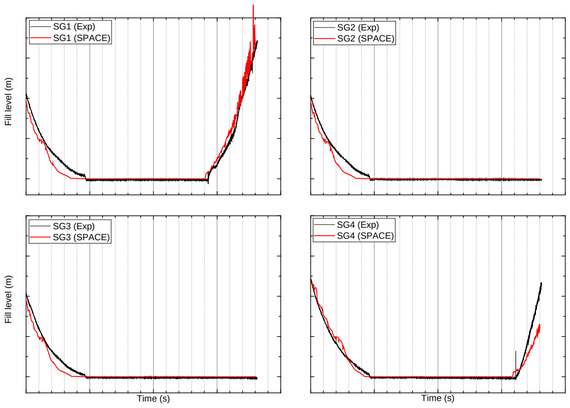

Fig 5. Comparison of SG fill level between PKL H2.2 test data and SPACE calculation

3. Conclusions

To assess the predictability of the SPACE code for multiple failure accidents, PKL test, located in Germany, for the station black out (SBO, PKLIII H2.2) was simulated. The SPACE modeling for PKL test facility was properly conducted and the results of initial conditions for the transient calculation have a good agreement with the test data. The time for opening of pressurizer relief valve in SPACE calculation is later than the test results because it has a different tendency of a sudden rising of core exit temperature from the perspective on core liquid level between test and SPACE code. Toward the end of scenario, there is also a discrepancy of the primary pressure. Because the primary pressure behavior, caused by the hear removal in steam generator, after activation of EFWS is not well predicted. We will conduct sensitivity study on the amount of EFWS injection to improve the predictability of SPACE for PKL H2.2 test.

Acknowledgement

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry and Energy(MOTIE) of the Republic of Korea. (No.20161510101840)

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