Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

MARS-LMR modeling for the post-test analysis of Phenix End-of-Life natural circulation

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1. Introduction

For a successful design and analysis of Sodium-cooled Fast Reactor (SFR), it is required to have a reliable and well-proven system analysis code. To achieve this purpose, KAERI is enhancing the modeling capability of MARS code by adding the SFR-specific models such as pressure drop model, heat transfer model and reactivity feedback model. This version of MARS-LMR will be used as a basic tool in the design and analysis of future SFR systems in Korea. Before wide application of MARS-LMR code, it is required to verify and validate the code models through analyses for appropriate experimental data or analytical results.

The end-of-life test of Phenix reactor performed by the CEA provided a unique opportunity to have reliable test data which is very valuable in the validation and verification of a SFR system analysis code. The KAERI joined this international program of the analysis of Phenix end-of-life natural circulation test coordinated by the IAEA from 2008. The main test of natural circulation was completed in 2009. Before the test the KAERI performed the pre-test analysis based on the design condition provided by the CEA. Then, the blind post-test analysis was also performed based on the test conditions measured during the test before the CEA provide the final test results. Finally, the final post-test analysis was performed recently to predict the test results as accurate as possible. This paper introduces the modeling approach of the MARS-LMR used in the final post-test analysis and summarizes the major results of the analysis.

2. Modeling of PHENIX natural circulation test

Phenix is a medium-sized pool-type SFR successfully operated for 35 years since 1973. The original thermal power from Phenix core was 540 MW, which was transported to power conversion system through three primary loops formed in a large reactor vessel. However, the reactor has been operated at a limited power of 350 MW through two secondary loops since 1993 after some reactor scrams due to unidentified reason still investigating.

The natural circulation test was performed as a part of Phenix end-of-life thermal-hydraulic tests to verify the initial formation and efficiency of natural circulation in Phenix design. The natural circulation test was performed for two days from June 22 to June 23, 2009. To achieve the initial condition for the test, the reactor power started to be decreased from 350 MWth to 120 MWth by decreasing the speed of primary pumps from 540 rpm to 350 rpm. The secondary pump speed was also decreased to 390 rpm. The main test was started by decreasing the feedwater flow rate and a condition of steam generator (SG) dryout was reached. After the SG dryout, the reactor power decreased by temperature feedback, thus, the core inlet temperature increased and the core outlet temperature decreased. Finally, the reactor was scrammed manually when the temperature difference between the IHX primary inlet and secondary inlet was about 15 K. The primary pumps were tripped at 5 second after the reactor trip [1]. The main plant parameters measured during the test includes primary pump speed, feedwater flow rate at SG, temperature at primary pump outlet, core power, temperature at outlet of subassemblies, IHX inlet temperature, and etc.

In the blind post-test analysis, the modeling for intermediate system, primary pump, and reactor power was eliminated by the use of measured boundary conditions provided by the CEA [2]. For the blind post-test analysis of natural circulation test with the MARS-LMR code [3], the same nodalization developed for the pre-test analysis is utilized. Further, the modeling approaches for the primary system are maintained to be the same with those used for the pre-test analysis.

For the post-test calculation with the MARS-LMR code, the KAERI has reinforced the modeling for heat structures in hot pool, heat structures in cold pool, steel structures in core, heat loss from roof and vessel, and core outlet region flow path. The secondary coolant flow rate through the IHXs, which is one of the boundary conditions, has also been corrected.

3. Post-test analysis results

The major parameters measured in the Phenix natural circulation test include primary coolant temperatures at pump inlet, IHX inlet, IHX outlet, and secondary temperatures at IHX outlet. The hot pool level and cold pool level were also measured in the test. The post-test results predicted by the MARS-LMR were compared with the measured data below.

The pump inlet temperature predicted in the post-test analysis before 1800s shows an enhanced result compared to the blind analysis. The trend of the test data is well simulated in the post-test analysis with 10°C over-estimation. As a result of the over-prediction in pump inlet temperature during the early stage of the transient, the pump inlet temperature predicted by the MARS-LMR shows a continuous decrease until the time of SG opening. The Phenix data shows a different trend, a decrease followed by an increase. The MARS-LMR predicts the test data accurately after the opening of SG casing as shown in Fig. 1.

The MARS-LMR under-predicts the temperature at primary IHX outlet before the pump trip. This underestimation is related to the lower IHX inlet temperature. However, the drastic temperature decrease after the scram followed by the primary pump trip is not described in the MARS prediction. This discrepancy can be understood if one considers that the temperature is measured at one point at IHX outlet and the prediction is for a large volume of cold pool near the IHX out region. After the pump trip, MARS-LMR simulates the test data quite accurately. The maximum deviation of the prediction from the test data does not exceed 10°C as shown in Fig. 2.

The general trend of the MARS-LMR prediction of pool levels is consistent with the test data. The initial pool levels and the level increase before the scram are predicted very accurately by the MARS-LMR. After the reactor scram and the primary pump trip, the level difference between the hot pool and the cold pool decreases due to the loss of pump head, which causes the decrease of hot pool level and the increase of cold pool level. The predicted level difference after the pump trip is 10 cm higher than the measured level difference. The behavior of hot pool level is shown in Fig. 3.

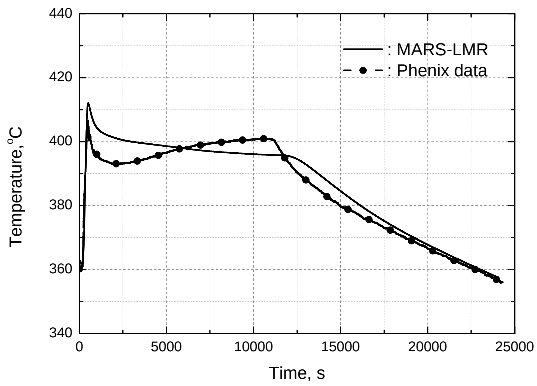

Fig. 1. The measured and the predicted pump inlet temperatures.

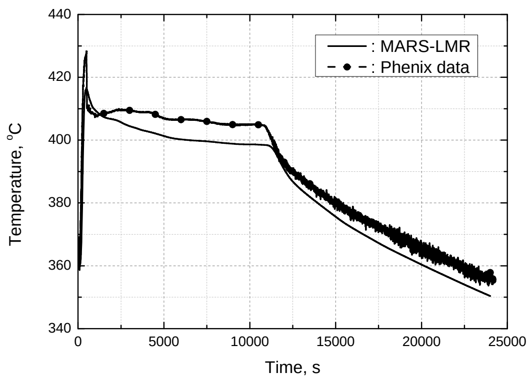

Fig. 2. Comparison of the predicted primary IHX outlet temperature with test data.

Compared to the blind post-test analysis, the core flow rate decreases to negative flow after the pump stop and it remains negative for about 100s. This change is caused by the modification of nodalization for core outlet region, which suggests that more sensitivity study on the nodalization effect is necessary.

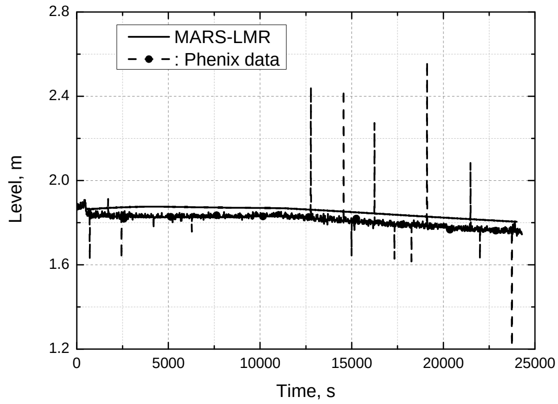

Fig. 3. Comparison of the predicted hot pool level with test data.

4. Summary

The post-test analysis of the Phenix natural circulation was performed with the MARS-LMR code. In the early phase before the primary pump trip, the MARS-LMR describes the heat-up process correctly by the enhanced modeling of steel structures in the core and pool regions. In the mid phase before the opening of SG casing, the MARS-LMR reproduces the drop of core outlet temperature successfully. However, the increase of core outlet temperature is delayed for 200s due to the reverse flow through the core just after the pump trip and the delayed development of natural circulation. Further studies on the nodalization effect are needed in the future. In the later phase after the opening of SG casing, the heat removal rate is increased by the opening of the SG opening. The general trends of the Phenix data are well predicted with the MARS-LMR code in this phase

Acknowledgements This work has been performed through the collaboration between CEA and KAERI in the frameworks of the IAEA coordinated research project (CRP) on Phenix End-of-Life tests.

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