Blind post-test analysis of Phenix End-of-Life natural circulation test with the MARS-LMR

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1. Introduction

KAERI is developing a system analysis code, MARS-LMR, for the application to a sodium-cooled fast reactor (SFR). This code will be used as a basic tool in the design and analysis of future SFR systems in Korea. Before wide application of a system analysis code, it is required to verify and validate the code models through analyses for appropriate experimental data or analytical results. The MARS-LMR code has been developed from MARS code which had been well verified and validated for a pressurized water reactor (PWR) system. The MARS-LMR code shares the same form of governing equations and solution schemes with MARS code, which eliminates the need of independent verification procedure. However, it is required to validate the applicability of the code to an SFR system because it adopts some dedicated heat transfer models, pressure drop models, and material properties models for a sodium system.

Phenix is a medium-sized pool-type SFR successfully operated for 35 years since 1973. This reactor reached its final shutdown in February 2009. An international program of Phenix end-of-life (EOL) test was followed and some valuable information was obtained from the test, which will be useful for the validation of SFR system analysis code. In the present study, the performance of MARS-LMR code is evaluated through a blind calculation with the boundary conditions measured in the real test. The post-test analysis results are also compared with the test data generated in the test.

2. PHENIX EOL natural circulation test

As a part of Phenix end-of-life thermal-hydraulic tests, a natural circulation test has been performed to verify the initial formation and efficiency of natural circulation in Phenix design. 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 of Phenix EOL 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 at 3 p.m. At 5:30 p.m. the power reached to the target value of 120 MWth. The speed of primary pumps was decreased from 540 rpm and it reached to 350 rpm. The secondary pump speed was also decreased to 390 rpm but the time duration for this control was not monitored clearly.

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. At about 3 hours after the initiation of main test, the windows of SG were opened and the air cooling was activated with higher cooling rate for 4 hours. Another test procedure was to investigate the air cooling mode in the SG. For this, the temperatures were monitored from the thermocouples installed at the chimneys of SG. The natural circulation test was finished at 21 hours after the start of the main test [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.

3. Blind post-test analysis

Before the release of test results, all participating organizations to the international program on Phenix EOL tests were asked to perform a blind post-test analysis with their own codes. In the blind post-test calculation, the modeling for intermediate system, primary pump, and reactor power was eliminated by the use of measured boundary conditions provided by the CEA [2]. This approach enables us to remove any distortion from the modeling of boundary conditions, thus, it is possible to focus on the assessment of code models for the description of natural circulation in the primary system. The primary system and the interface between the primary and secondary, i.e., the intermediate heat exchangers (IHXs) are fully modeled for the blind post-test analysis.

For the blind post-test analysis of natural circulation test with the MARS-LMR code, 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 [3]. As a first step of the analysis, the steady condition for 350 MW is simulated. From this condition, the condition for 120 MW is derived by reducing the core power, primary pump speed, and secondary flow rate gradually.

In the modeling of natural circulation, it is important to describe correctly the initial formation of natural circulation in the primary circuit. Therefore, it is required to predict the temperature distribution in hot pool and cold pool. In the present study, the thermal hydraulic behavior during the transient is simulated with a one-dimensional approach. This could cause some distortion in mixing characteristics in core outlet, hot pool, IHX outlet, and cold pool. Therefore, the primary purpose of the present study is to qualify the capability of 1-D modeling of MARS-LMR code for the description of a natural circulation condition.

In Fig. 1, the core outlet temperature predicted with the MARS-LMR is compared with the measured test data. It is found that the MARS-LMR over-predicts the core outlet temperature at the initial stage of natural circulation. The prediction for the later phase of the transient shows a consistent trend with the test data within about 10 ^{o}C of temperature deviation.

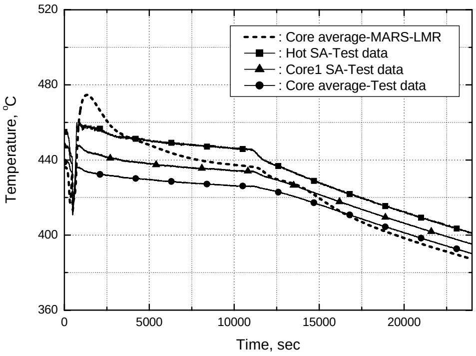

Fig. 1. The measured and the predicted core outlet temperatures.

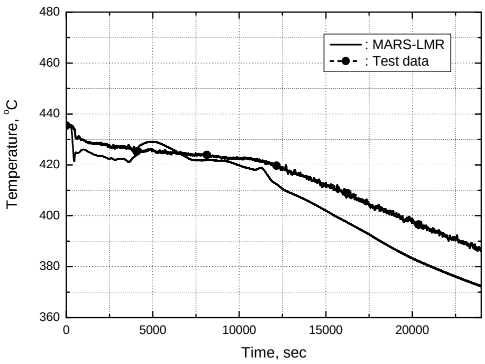

Fig. 2. Comparison of the predicted primary IHX inlet temperature with test data.

In Fig. 2, the IHX inlet temperature in primary side is given. The MARS-LMR predicts lower initial IHX inlet temperature in the early phase but general behaviors are predicted rather correctly. In Fig.3, the predicted temperature at secondary IHX outlet is compared with the measured data. The predicted temperature is higher than the test data through whole period of transient except the very short period of initial stage of natural circulation formation.

The above results suggest that there exist some mismatch between the predicted and the measured in the mixing behaviors in hot and cold pools. This is presumed to be a main reason of higher initial core inlet and outlet temperatures in the MARS-LMR simulation. The modeling of reactor vessel cooling flow path could be another reason of the mismatch between the prediction and test data. The other finding obtained from the present analysis is that the heat removal through IHXs predicted by the MARS-LMR is quite larger than the real quantity of heat transfer in the test.

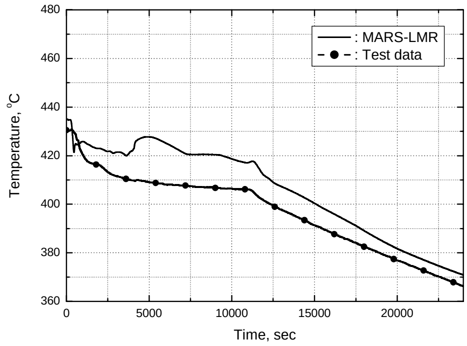

Fig. 3. Comparison of the predicted secondary IHX outlet temperature with test data.

4. Summary

A blind post-test analysis of Phenix end-of-life natural circulation test was performed to evaluate the applicability of the MARS-LMR code to SFR system analysis. Judging from the comparison between the predicted and the measured data, it can be said that the MARS-LMR code simulates the general trend of natural circulation transient successfully. The effect of pool mixing and initial formation of natural circulation should be assessed further with an enhanced modeling for the vessel cooling system and also with a three-dimensional modeling of pool volumes in the future studies. The accuracy of the simulation with the MARS-LMR code is also expected to be enhanced by refining the heat loss through the vessel surface and the top of the vessel roof.

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