Multi-dimensional approach of MARS-LMR for the analysis of Phenix End-of-Life natural circulation test

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1. Introduction

Phenix is one of the important prototype sodium-cooled fast reactors (SFR) in nuclear reactor development history. It had been operated successfully for 35 years by the French Commissariat à l'énergie atomique (CEA) and the Electricite de France (EdF) achieving its original objectives of demonstrating a fast breeder reactor technology and of playing the role of irradiation facility for innovative fuels and materials. After its final shutdown in 2009, CEA launched the Phenix End-of-life (EOL) test program [1]. It provided a unique opportunity to generate reliable test data which is inevitable in the validation and verification of a SFR system analysis code.

KAERI joined this international collaboration program of IAEA CRP and has performed the pretest analysis and post-test analysis utilizing the one-dimensional modeling of the MARS-LMR code, which had been developed by KAERI for the transient analysis of SFR systems. Through the previous studies, it has been identified that there are some limitations in the modeling of complicated thermal-hydraulic behaviors in the large pool volumes with the one-dimensional modeling. Recently, KAERI performed the analysis of Phenix EOL natural circulation test with multi-dimensional pool modeling, which is detailed below.

2. Multi-dimensional modeling of Phenix test

The main purpose of Phenix natural circulation test is to verify the initial formation and efficiency of natural circulation in Phenix design. This test provides important data to validate the applicability of system codes to natural circulation condition. Phenix is a medium-sized pool-type SFR originally operated with the thermal power of 540 MW. However, there occurred some unidentified reactor scrams at Phenix. After that, the reactor has been operated at a limited power of 350 MWth. The natural circulation test was started at the initial power of 120 MWth. To achieve this initial condition for the test, the reactor power was decreased from 350 MWth to 120 MWth by decreasing the speed of primary pumps from 540 rpm to 350 rpm. The main transient of natural circulation was begun by decreasing the feed flow and introducing steam generator (SG) dryout condition. After the SG dryout, the reactor power decreased by temperature feedback, thus, the core inlet temperature increased and the core outlet temperature decreased. The reactor was scrammed manually five minutes after the SG were dried out when temperatures on the secondary side of the IHX were quite isothermal. The three primary pumps were also stopped manually at 5 second after the reactor trip. The main plant parameters measured during the test include 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 analysis of the test with MARS-LMR code, the modeling for intermediate system, primary pump, and reactor power was eliminated by the use of measured boundary conditions provided by the CEA [2]. The core subassemblies were modeled one-dimensionally into 7 different flow channels and the active 4 IHXs were modeled independently with one-dimensional nodes. On the contrary, the hot and cold pools were described with the multi-dimensional nodalization as shown in Fig. 1. The hot pool region from the core outlet to the inlet of IHXs has been divided into 8 axial nodes, 4 radial nodes, and 6 azimuthal nodes. Further, the cold pool region has been modeled with 12 axial nodes, 1 radial node, and 9 azimuthal nodes.

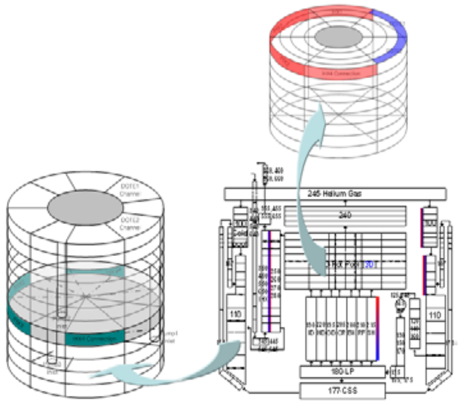

Fig. 1. Multi-dimensional modeling of Phenix pools.

3. Analysis results

As described in the previous studies [3,4], the one-dimensional approach of MARS-LMR code has limitation in predicting the behaviors of measured data. Usually, the limitations were found in the prediction of temperatures after the pump trip around which very complicated flow regimes could be developed in the pool regions.

The pump inlet temperatures predicted with the one-dimensional and the multi-dimensional pool modeling is compared in Fig. 2. It is found that the one-dimensional approach over-predicts the initial temperature increase.

Therefore, it shows continuous decrease until the SG opening time. The temperature at pump inlet predicted by the multi-dimensional pool models shows clear early peak, even though it is slightly under-predicted, thus it gives accurate prediction after 2,500 seconds.

The effect of multi-dimensional modeling is also found in the prediction of the temperature at primary IHX outlet region. As shown in Fig. 3, the rate of initial temperature increase until the manual reactor trip is well predicted with the one-dimensional pool modeling. However, the sudden fall-down of Phenix data just after the reactor trip is not predicted with the one-dimensional approach. On the contrary, the fall-down behavior appears with the multi-dimensional approach even though the rate of initial temperature increase is slightly underestimated.

The most remarkable influence of the modeling of pool behavior is found in the prediction of core outlet temperature measured at the exit of inner core region. It is clearly shown that the multi-dimensional pool model results in much improved prediction of the Phenix test data as shown in Fig. 4. These results suggest that the thermal-hydraulic characteristics formed in the hot pool region from core outlet to the IHX inlet and in the cold pool from the IHX exit to the primary pump inlet are described well when they are modeled in multi-dimensionally. This means that an enhanced modeling capability of the multi-dimensional model is expected in the description of the flow behaviors in a large pool.

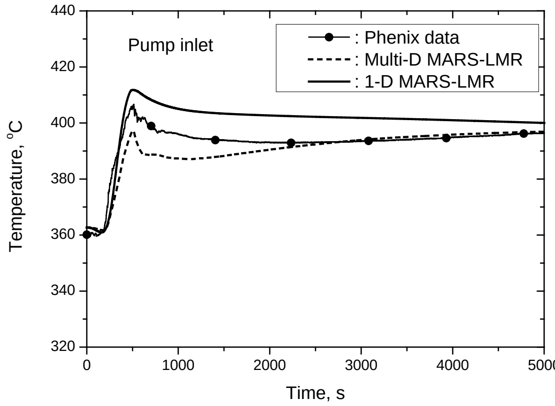

Fig. 2. Pump inlet temperatures predicted with MARS-LMR.

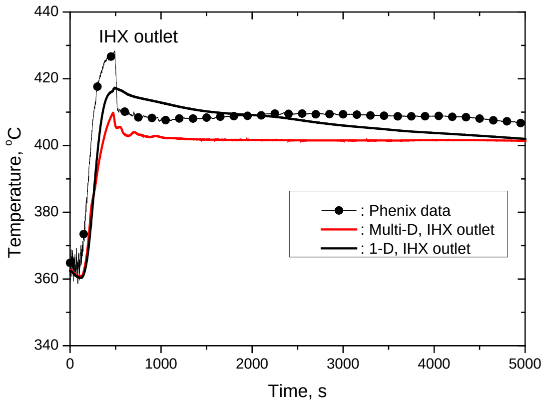

Fig. 3. Pump inlet temperatures predicted with MARS-LMR.

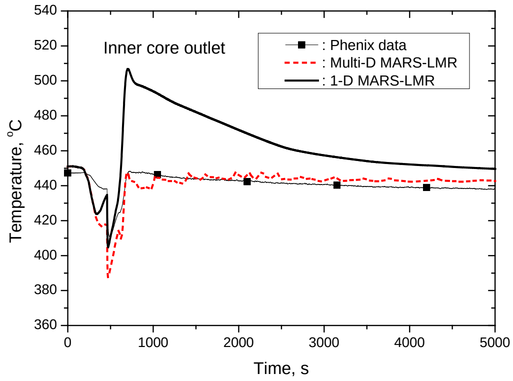

Fig. 4. Inner core outlet temperatures predicted with MARS-LMR.

4. Summary

The natural circulation test data obtained from the Phenix EOL test was analyzed with the MARS-LMR multi-dimensional pool modeling. Judging from the comparison of the analysis results with the predictions in the previous studies, which adopted one-dimensional pool modeling, a multi-dimensional pool modeling gives much improved prediction of the test data with minimized distortion of the data trends. The present study suggests that the correct modeling of pool behaviors is inevitable in the analysis of a pool-type SFR.

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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