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Pre-analysis of Phenix End-of-Life Thermal-hydraulic tests with the MARS-LMR Code

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1. Introduction

A prototype SFR, PHENIX has been operated by the French Commissariat à l'énergie atomique (CEA) and the Electricite de France (EdF) since 1973. Through the successful operation for 35 years, PHENIX has achieved its original objective to demonstrate a fast breeder reactor technology and also played an important role as an irradiation facility for innovative fuels and materials. Since its first operation, PHENIX has accumulated about 4,300 equivalent full power days (EFPDs) of operational experience and it reached its final shutdown in 2009. Before the decommissioning of PHENIX, the CEA started a PHENIX end-of-life (EOL) test program and opened it for international collaboration to share the valuable information from the test. The KAERI joined this program to utilize the unique opportunity to validate its SFR system analysis code, MARS-LMR which will be a basic tool in future SFR development.

2. PHENIX EOL tests

Phenix is equipped with 3 primary pumps and 6 IHXs to transfer the 565 MW of thermal power from core to steam generators. Since 1993 after some reactor scrams due to unidentified reason still investigating, the reactor is operated at a limited power of 350 MW through two secondary loops. Now, the three primary pumps are operating at 540 rpm to maintain the primary flow at 1840 kg/s [1]. On the contrary, two secondary pumps and 4 IHXs are working for the heat transport. The other secondary circuit is filled with sodium but not operating and the two IHXs connected to this circuit are replaced by closed cylindrical structures called DOTE for cold pool temperature profile.

Two thermal-hydraulic tests, an asymmetry test and a natural circulation test, are planned in the EOL tests. During an asymmetrical transient there occur some complicated thermal-hydraulic phenomena such as buoyancy flow, thermal stratification, and three-dimensional effects in the reactor vessel. The main purpose of this test is to obtain the data on pool temperature stratification applicable for the validation of system code capability to predict asymmetrical situations. This data would be also useful for the evaluation of CFD code capability to predict the three-dimensional thermal loadings.

The natural circulation test is performed to verify the initial formation and efficiency of natural circulation in Phenix design. The data obtained from this test is significant to validate the applicability of system codes to natural circulation condition. The initial conditions for the transient are determined through a steady state analysis for 120 MW

3. Pre-test analysis

Before the main EOL tests, pre-test analyses are performed to evaluate the capability and limitation of the MARS-LMR code. For the blind calculation at the pre-analysis stage, the CEA has not provided detailed condition for secondary system except the IHX inlet/outlet temperatures and flow rate through the secondary system. Therefore, the secondary and tertiary systems are represented as boundary conditions. The primary system and the interface between the primary and secondary, i.e., the intermediate heat exchangers (IHXs) are fully modeled for the pre-test analysis.

For the pre-test analysis the Phenix primary system and IHXs are nodalized as shown in Fig. 1. Total 981 subassemblies in the core are modeled for pre-test analysis. The core subassemblies (S/As) are divided into 7 flow channels. The active 4 IHXs are modeled independently to investigate the asymmetric flow condition. The cold pool is modeled by the two axial nodes, 100 and 110 having 5 and 6 sub-volumes, respectively. The containment vessel cooling system is modeled to match the flow balance in the primary system. The flow path of vessel cooling system is quite complicated. However, it is simplified in the modeling as shown in Fig. 1.

The asymmetry test is characterized by the imbalance of cooling rate between intermediate loop 1 and 3. To cause this transient the intermediate pump in loop 1 is tripped and a fast rod insertion is followed to reduce the core power. Another intermediate pump in loop 3 is controlled to decrease the pump speed linearly. Finally,

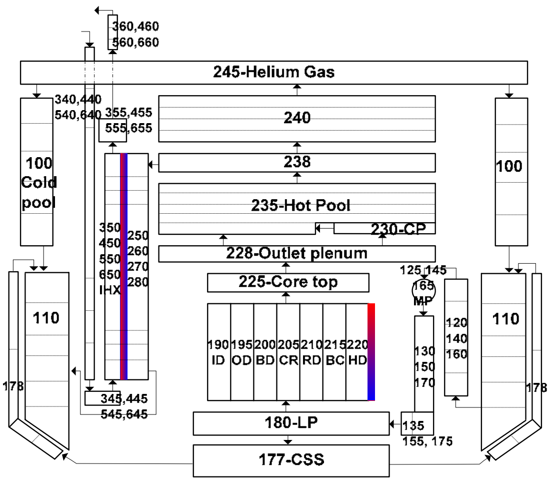

Fig. 1. Nodalization for pretest analysis with MARS-LMR.

the reactor is scrammed at a core power of about 50 MW. The initial core power is 350 MW and the primary pumps are operating with the speed of 540 rpm [2].

By the influence of one secondary pump trip followed by the decreased speed of the other pump the core inlet and IHX outlet temperatures increase abruptly. Therefore, the temperatures in cold pool region also increase during the first part of the test. Fig. 2 compares the temperature at primary IHX outlet obtained from one-dimensional models of MARS-LMR and DYN2B. As shown in the figure, the very oscillatory temperature behavior is predicted with one-dimensional MARS-LMR model. One of the main reasons of this trend is presumed to be the delay in temperature propagation by the volume averaging adopted in the MARS-LMR. In the figure, it is also found that the early temperature peak is higher in MARS-LMR calculations than the peak predicted by DYN2B code. However, the difference is not so remarkable.

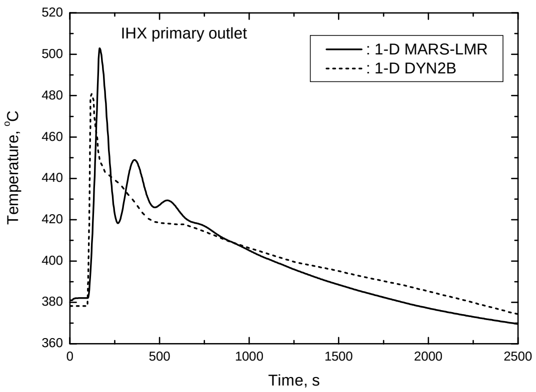

Fig. 2. Predicted temperatures at IHX outlet for asymmetry test.

The primary purpose of the present study is to evaluate the capability of 1-D modeling of MARS-LMR code for the description of a natural circulation condition. To achieve the initial condition for the natural circulation test, the reactor power is decreased from 350 MWth to 120 MWth. The speed of primary pumps is also decreased from 540 rpm to 350 rpm. The secondary pump speed is decreased to 390 rpm [3]. The main test is started by decreasing the feedwater flow followed by the SG dryout. After the SG dryout, the reactor power decreases by temperature feedback, thus, the core inlet temperature increases and the core outlet temperature decrease. Finally, the reactor is scrammed manually when the temperature difference between the IHX primary inlet and secondary inlet is about 15 K. The primary pumps are tripped at 5 second after the reactor trip.

In Fig. 3, the core outlet temperatures predicted by two 1-D codes, MARS-LMR and DYN2B, are provided. A direct comparison between the two codes is not so meaningful because the exact modeling methodology for DYN2B is not given. Just judging from the obtained results in Fig. 3, the MARS-LMR predicts a larger temperature increase than the DYN2B after the initial shrinkage and the trend of temperature change is rather mild. The higher core outlet temperature predicted by the MARS-LMR is analyzed to be caused by the higher reactor power at the moment of reactor scram. The temperatures at SA outlets have similar trends.

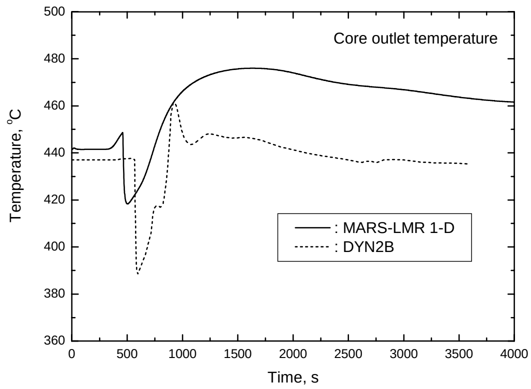

Fig. 3. Predicted temperatures at core outlet for natural circulation test.

4. Summary

An international cooperation program on the Phenix end-of-life test has been initiated to provide a worldwide opportunity to validate an SFR system analysis code. The KAERI joined this program to utilize this unique opportunity to evaluate the capability and limitation of the MARS-LMR code. As the first step of the job, a pre-test analysis is performed to prepare a basic modeling for the evaluation of the thermal-hydraulic test data to be produced. In the pre-test analysis, one-dimensional thermal-hydraulic behaviors for asymmetrical test and also for natural circulation test are analyzed. It is found that the description of pool behavior is important for the prediction of thermal-hydraulic transients in SFR and a one-dimensional approach is not adequate to describe the pool behavior. A three-dimensional approach is recommended to have an improved prediction.

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