Validation of MARS-LMR Code using EBR-II Unprotected Loss of Heat Sink Test

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1. Introduction

KAERI has designed the prototype Gen-IV sodium-cooled fast reactor (PGSFR). And to analyze various accident conditions, MARS-LMR code has developed in safety analysis team. The MARS-LMR is based on the MARS code and SFR features including liquid metal heat transfer and additional reactivity feedback models are supplemented in that. Recently, in order to validate MARS-LMR code, the EBR-II BOP tests are calculated. The EBR-II BOP test is an unprotected loss of heat sink, which is initiated by trip of an intermediate pump. The major concerns of this benchmark analysis are not only thermal-hydraulic and reactivity feedbacks since the reactor is not scrammed. To simplify the benchmark calculation, at first step, the calculation is conduction without reactivity feedback to validate the thermal-hydraulic behavior. At the second step, sensitivity test for reactivity feedback models are conducted. Finally, whole reactor is validated with pre-validated models for both thermal-hydraulic and reactivity feedbacks. However, still there are unknown parameters to obtain better prediction. Therefore, additional validation calculations are necessary to understand behavior of EBR-II ULOHS Test.

2. EBR-II Model for ULOHS

2.1 EBR-II Models

EBR-II modeling is previously achieved during IAEA Coordinated Research Program for EBR-II SHRT benchmark analysis [1]. Fig. 1 shows nodalization of EBR-II for ULOHS. The core configuration of the EBR-II is very complex due to experimental reactor. So, the core is modeled with 10 channels including driver fuel, control rod, inner and outer reflector, blanket assemblies. The EBR-II has a single cold pool connected two primary pumps and one intermediate heat exchanger (IHX). The sodium flow is driven by these mechanical pumps and pumps outlet is bifurcated to high-pressure and low-pressure pipes, which are supply coolant to a high-pressure and low-pressure inlet plenums, respectively. The core flow is heated thru the active core region, then pass thru the outlet plenum, the Z-pipe, and the IHX inlet, in turn. Hot sodium is cooled by the IHX shell-side and the cooled sodium is supply to the cold pool again. A tube side in the IHX is treated as boundary in the EBR-II model. All EBR-II data is provided by Argonne National Laboratory (ANL) collaboration [2].

The unprotected loss of heat sink test is initiated by the reduction of tube-side flow in the IHX. Therefore, the heat removal capability in the IHX is reduced, as a result, the cold pool (core inlet) temperature is increased. However, increased coolant and structure temperatures make negative reactivity feedbacks in the core, so, the reactor power is inherently reduced, and the core outlet temperature is reduced. Finally, the reactor reached an equilibrium state again.

2.2 Boundary Conditions

The inlet and outlet in the IHX tube-side are treated as boundary. The inlet coolant flow is reduced as shown in Fig. 2. However, the flow rate in the shell-side is almost constant due to working of primary pumps. The tube-side temperature in the IHX is not changed. The test data is obtained by 4500 seconds. The boundary conditions are also provide by ANL collaboration [2].

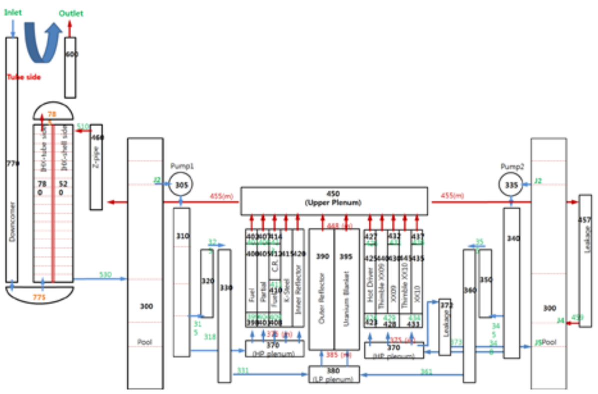

Fig. 1. Nodalization of EBR-II for MARS-LMR

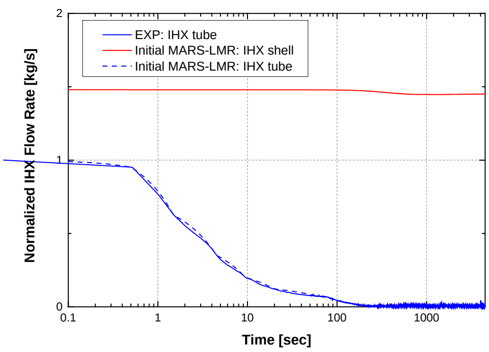

Fig. 2. Flow rates in the IHX during the EBR-II ULOHS

3. Benchmark Analyses

3.1 Initial Calculation

Based on the previous model used in EBR-II SHRT benchmark analyses [1], initial calculation for the ULOHS is conducted. The reactor power is reduced by reactivity feedbacks, however, the timing of feedback is late as shown in Fig.3. The reason of the late response is core coolant temperature rise is late as shown in Fig. 4. Therefore, the core power and coolant temperatures are over estimated in the early transient.

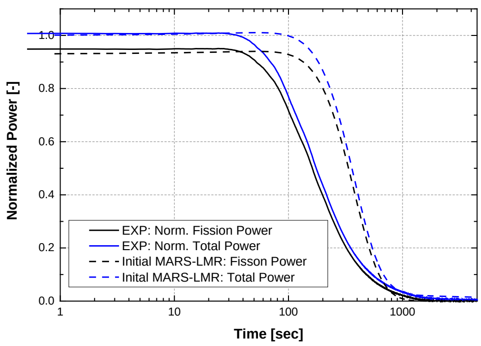

Fig. 3. Initial Calculation Result for EBR-II ULOHS: Reactor Power

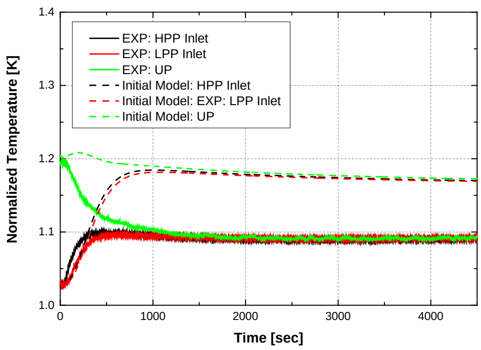

Fig. 4. Initial Calculation Result for EBR-II ULOHS: Core Temperatures

3.2 Calculation without feedbacks

An unprotected test has reactivity feedback between temperatures and reactor power, so it is very difficult to predict and understand the transient behaviors. Therefore, to simplify the calculation, the calculation without reactivity feedback, in other words, calculation using the measured power, is conducted. With these calculation, the validation of thermal-hydraulic model can be achieved. As shown Fig. 5, the reference calculation results shows much better prediction comparing the initial calculation due to appropriate reactor power. However, the temperatures are still high and timing of the rise is late. Based on the component calculations of reactor core and IHX, it was found that

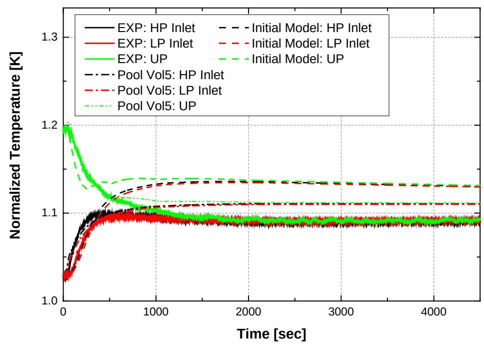

Fig. 5. No-feedback Calculation Result for EBR-II ULOHS: Core Temperatures

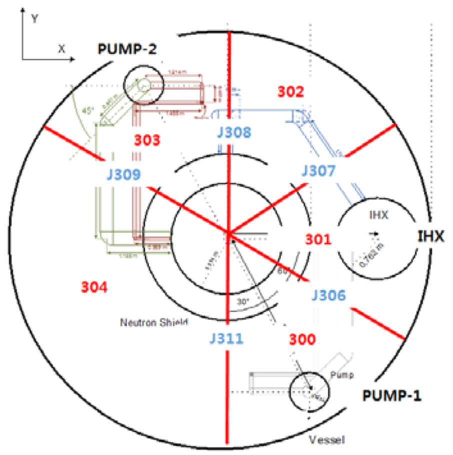

Fig. 6. Radial Locations for IHX and pumps in the EBR-II [3]

the component modeling has no issues. Thus, cold pool modeling is shown up to a possible reason. As shown in Fig. 1 cold pool consist of one dimensional and axial 6 volumes. The IHX outlet and pumps are connected to bottom of vol. no. 3 and no. 2, respectively. Therefore, the timing of core inlet temperature is governed by the modeling of flow path with 3rd volume in the cold pool model. In addition, the two pumps are radially located with different distance from the IHX as shown in Fig. 6. Therefore, semi-multi-dimensional pool model is adopted with radial 5 volumes (Fig.6). When this model is applied, core inlet temperature rise is faster than the initial model as shown in Fig. 5. Moreover, the peak temperatures are also approached to the experimental results. The temperature rise timing in this model is slightly faster than the experimental results. So, the higher resolution calculation is necessary to understand the flow pattern during the transient and to finalize and confirm the acceptable pool model.

3.3 Sensitivity for reactivity feedback models

With the five-volume pool model, feedback calculation is conducted. Comparing to initial calculation results (Fig.4), the temperature rise timing becomes better. However, the peak temperatures are

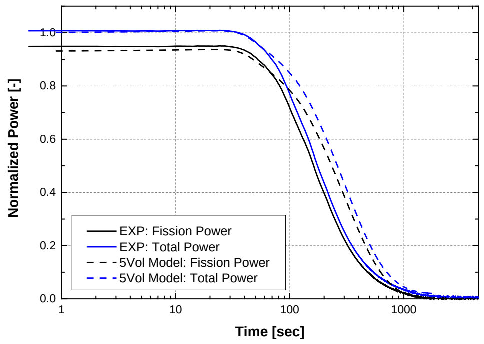

Fig. 7. Feedback Calculation Result for EBR-II ULOHS: Core Temperatures

still slightly higher than the experimental results comparing to results in Fig. 5. The reason is reactivity feedback is over-estimated during transient after about 60 sec as shown in Fig. 7. To understand the reactivity feedback behavior during the ULOHS test, the sensitivity tests for the reactivity feedback models are conducted. During the experience from EBR-II SHRT-45R benchmark calculation, it is observed that the axial expansion reactivity feedback can be over-estimated [1]. Therefore, in this study, the axial expansion reactivity feedback is assumed to 20% with similar value to that in the EBR-II SHRT-45R. Fig. 8-10 shows sensitivity results for the reactivity feedback models. CASE1, 2, 3, and 4 indicate 40%, 70%, 130%, and 160%, respectively. The most insensitive and sensitive reactivity feedback are the Doppler and the CRDL/RV expansion reactivity, respectively. The density reactivity initially gives negative feedback, however, positive feedback in the long term. The radial and CRDL/RV expansion reactivity shows negative feedback during whole transient.

Although the sensitivity test is achieved only for individual feedback, the power reduction rate in MARS-LMR is much lower than that in the experiment. Therefore, possible reason can be heat transfer in the structure expansion, such as radial and CRDL/RV expansions. The radial expansion is modeled with combination of a grid plate and assembly ducts in the core. And, the CRDL/RV expansion is modeled with control rod drive-line and reactor vessel. Therefore, the

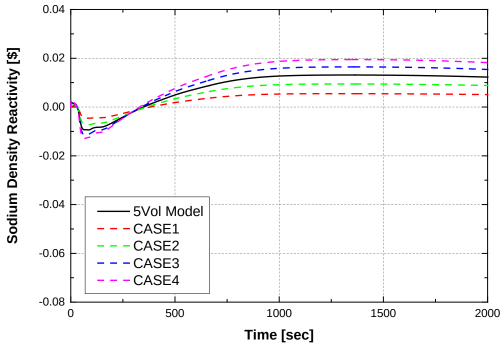

Fig. 8. Reactivity Feedback Sensitivity Results: Density

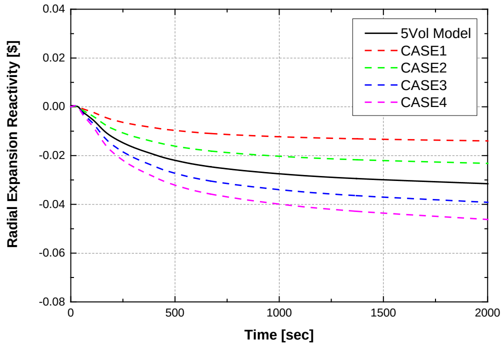

Fig. 9. Reactivity Feedback Sensitivity Results: Radial Expansion

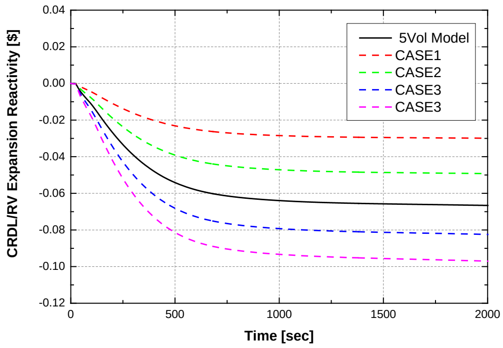

Fig. 10. Reactivity Feedback Sensitivity Results: CRDL/RV Expansion

sensitivity test for heat transfer between each structure and coolant will be checked.

4. Conclusions

To validate the MARS-LMR code with EBR-II ULOHS test data, at first simple calculation without reactivity feedback is conducted. From this calculation, it is found that the cold pool modeling is very important during the ULOHS transient, since the pool is major connection from the IHX outlet to the pumps inlet. Especially, in the case of non-symmetric locations of the IHX and pumps like an EBR-II, one dimensional model cannot be appropriate. Therefore, in this study, the cold pool is modeled with radial 5 volumes is applied to improve the prediction of flow path between the IHX and pumps.

A feedback calculation with the 5 volume model shows better prediction, especially in the feedback initiation. However, the reactor power is slightly higher than that in the experiment. In addition, sensitivity test for the reactivity feedback models are carried out to understand the characteristics during the EBR-II ULOHS transient. Most sensitive reactivity feedback model is the CRDL/RV expansion. And the Doppler reactivity is negligible. Only positive reactivity feedback is observed in the sodium density reactivity. Based on the sensitivity rest results, the power reduction rate is still lower than that in the experiment. Therefore, we can conjecture that the temperature change in the structure can be lower than the actual situation. As a next step, the sensitivity test for heat transfer model in the structures such as control rod driveline, assembly duct, grid plate, and assembly ducts, which are related to structural expansion reactivity feedbacks.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Research & Development Program of the National Research Foundation (NRF) grant funded by the Korean government MSIP (Ministry Science, ICT and Future Planning).

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