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Influence of Pool Modeling in the Analysis of Asymmetrical Test in Phenix Reactor

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1. Introduction

In a pool-type sodium-cooled fast reactor (SFR), all the main components of primary heat transport system (PHTS) such as coolant pumps, intermediate heat exchangers (IHXs), reactor core, upper core structure (UIS) including control rod drive mechanism are arranged in two big sodium volumes; the hot pool and the cold pool. A large quantity of sodium in the pool region provides a large thermal inertia, which is one of the advantages of pool-type SFR. In an abnormal or accident condition this thermal inertia mitigates the transient not to cause an abrupt change in sodium temperature, thus, operators are allowed to have a much longer grace time.

A problem is that the geometry of the pool volume is not so simple and it is also big enough to make associated thermal-hydraulic phenomena very complicated. Therefore, it is required to validate the applicability of a simple one-dimensional modeling which is frequently adopted for the simulation of a reactor system. In this study, the capability of one-dimensional approach and multi-dimensional approach of the MARS-LMR code [1] is evaluated. For this, the asymmetrical test of Phenix end-of-life (EOL) test is analyzed with two different pool modeling approaches.

2. Phenix EOL asymmetrical test

Phenix is a unique prototype SFR operated by the French Commissariat à l'énergie atomique (CEA) and the Electricite de France (EdF) since 1973. After a successful 35-year operation as a demonstration facility of a fast reactor technology and an irradiation facility, it reached its final shutdown in 2009 and the CEA started an end-of-life (EOL) test program and opened it for international collaboration to utilize the unique opportunity to validate SFR system analysis codes.

One of the EOL thermal-hydraulic tests is an asymmetrical test, which is characterized by the imbalance of cooling rate between intermediate loop 1 and 3. 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. 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 [2]. Finally, 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 to maintain the primary flow at 1840 kg/s [3]. The time duration of interest in this test is about 30 minutes. In the test performed on 29 May 2009, the speed of secondary pumps was increased to control the temperature difference between the primary and secondary circuits at about 35 minutes after the initiation. The decrease of the primary pump speed was followed for the same purpose.

3. Analysis with MARS-LMR

Even though Phenix is equipped with 3 primary pumps and 6 IHXs, the reactor has been operated at a limited condition with two secondary pumps and 4 IHXs since 1993. All three primary pumps have been running to maintain the required primary flow. The other secondary circuit is filled with sodium but not operating and the two IHXs connected to this circuit have been replaced by closed cylindrical structures called DOTE for cold pool temperature profile.

For the analysis of an asymmetrical test, the Phenix system is modeled with one-dimensional nodalization as shown in Fig. 1. A total of 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 7 and 12 sub-volumes, respectively. The containment vessel cooling system is modeled to match the flow balance in the primary system.

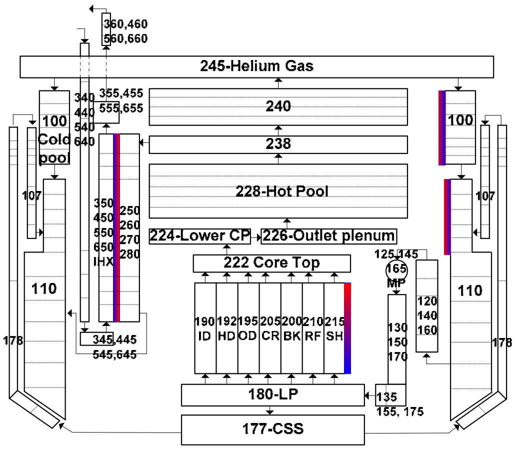

Fig. 1. One-dimensional nodalization for Phenix reactor.

The sodium temperatures at the primary IHX outlet obtained from one-dimensional models of MARS-LMR and DYN2B are compared in Fig. 2. The nodalization for DYN2B code has been tuned to match the thermal-hydraulic experimental data during the design of the Super-Phenix. 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.

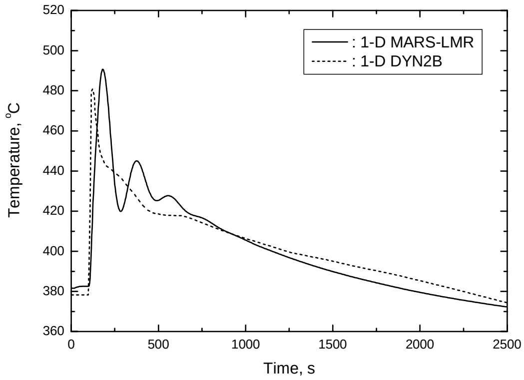

Fig. 2 IHX outlet temperatures predicted with 1-D models.

In other words, the reason making the one-dimensional MARS-LMR analysis unrealistic is presumed to be the limitation to describe the thermal-hydraulic behaviors in the hot pool. Fortunately, the MARS-LMR code is equipped with a multi-dimensional model for a large volume such as downcomer, hot pool and cold pool. To analyze the effect of hot pool modeling on the MARS-LMR calculation of asymmetrical test the volume from outlet plenum to hot pool just below the IHX inlet region is modeled as a multi-dimensional component as shown in Fig. 3.

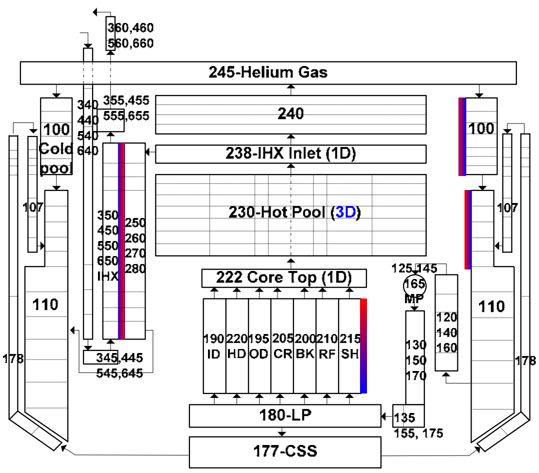

Fig. 3. Mult-D hot pool nodalization for Phenix reactor.

The hot pool region is divided into 4 segments in radial direction and 6 segments azimuthally. The influence of this multi-dimensional hot pool modeling on the primary side IHX outlet temperature is described in Fig. 4. It is found that the unrealistic oscillations in hot pool temperature, core inlet temperature, and IHX outlet temperature are almost removed mainly due to the improved prediction of mixing and circulation by buoyancy in the hot pool region.

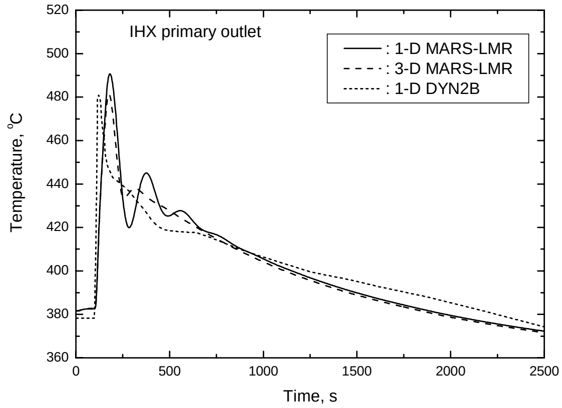

Fig. 4 IHX outlet temperature predicted with multi-D model.

4. Summary

To evaluate the applicability of one-dimensional approach and multi-dimensional approach of the MARS-LMR code to the simulation of hot pool behavior, an asymmetrical test of Phenix EOL test is analyzed with two different pool modeling approaches. The one-dimensional pool modeling results in an oscillatory behavior in pool temperatures, which is estimated to be unrealistic. The multi-dimensional approach is believed to be more realistic than the prediction by one-dimensional approach and it gives a very similar trend with a well validated one dimensional code, DYN2B. In future studies, the cold pool is also simulated multi-dimensionally and the real test data will be analyzed.

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