Simulation of Phenix EOL Asymmetric Test

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1. Introduction

The asymmetric test of End-Of-Life (EOL) tests on the Phenix plant was used for the evaluation of the MARS-LMR in the Generation IV frame as a part of the code validation. The purpose of the test is to evaluate the ability of the system code to describe asymmetric situations and to identify important phenomena during asymmetrical transient such as a three dimensional effect, buoyancy influence, and thermal stratification in the hot and cold pools. 3-dimensional sodium coolant mixing in the pools has different characteristics from the one dimensional full instantaneous mixing. The velocities and temperatures at the core outlet level differ at each sub-assembly and the temperature in the center of the hot pool may be high because the driver fuels are located at the center region. The temperatures in the hot pool are not the same in the radial and axial locations due to the buoyancy effect. The temperatures in the cold pool also differ along with the elevations and azimuthal directions due to the outlet location of IHX and the thermal stratification.

2. Description of the asymmetric test

The Power of Phenix plant is 351.7 MW_{th} and the plant is equipped with three mechanical pumps and 6 IHXs[3]. The core consist of 110 driver fuel subassemblies, 6 control rods, 1 shutdown rod, 86 blankets, 212 reflectors and 1062 shield assemblies. Two IHXs were closed due to the malfunction of the plant and some measuring instruments were installed in the closed IHX bottom elevation.

For the asymmetry test the plant would operate under the thermal power of 350 MW_t. The transient is triggered by the sudden trip of one secondary pump. A few seconds later, the other secondary pump speed is linearly decreased and the speeds of two pumps are maintained as the reduced levels. The reduced flow of the secondary loop causes the primary sodium coolant temperature to increase and finally the reactor is tripped.

3. MARS-LMR Nodalizations for Phenix system

For the simulation of Phenix EOL asymmetry test, we used 3 nodalizations; one-dimensional nodal scheme for the PHTS, nodal scheme with a two dimensional cold pool, and multi-dimensional nodal scheme for both hot pool and cold pool.

MARS-LMR nodal schemes is shown in Fig. 1. The core is divided into 7 parallel channels; inner driver fuel subassemblies(ID), hot driver fuel assembly(HD), outer driver fuel assemblies(OD), control rods(CR), blanket subassemblies(BK), reflectors(RF), and B4C shield and in-vessel storages(SH). The 7 core channels are connected with the common core top.

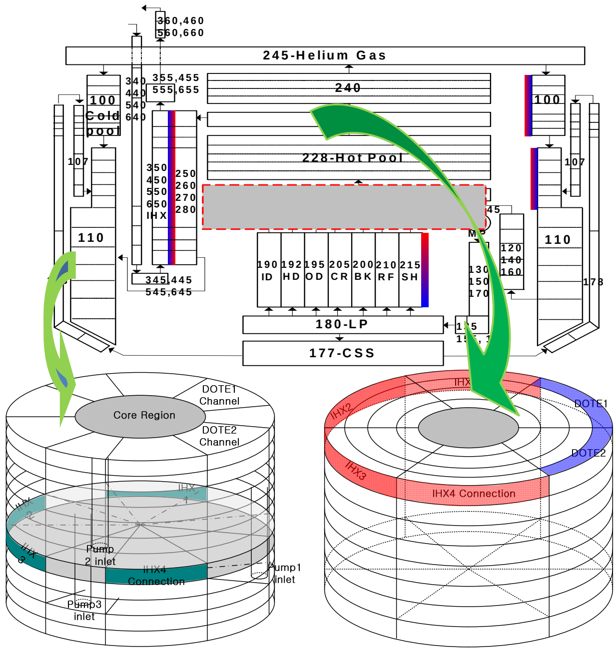

Fig. 1 MARS-LMR Nodalizations for Phenix plant

The hot pool was axially segmented to 10 volumes and the inlets of 4 IHXs in primary side were linked with the middle of the hot pool. The primary sodium flows down the 4 IHX shell sides and is dumped into the cold pool. The cold pool was also modeled as the 19 axial segments and the 3 pump inlet pipes are connected with the cold pool. Three pumps were modeled using an imbedded pump component of MARS-LMR code and the pump coastdown in the transient simulation were modeled using the pump speed from the test data. The pump outlet pipes are jointed with the inlet plenum. Vessel cooling pipes are also connected with the inlet plenum. The only IHX tube side was modeled in the secondary side and the test data were used as the boundary conditions at the inlet and outlet of the IHX secondary side.

For sensitivity study, the hot pool are 3-dimmensionally nodalized as shown in the bottom right side of Fig. 1. The 3-D hot pool is composed of 4 radial rings, 6 azimuthal sections, and 8 axial nodes. 4 radial rings represent each zone of the fuel types and 6 azimuthal sections are to consider 2 closed IHXs (DOTE1, DOTE2), 4 IHXs.

The cold pool are also nodalized with a 2-dimensionally. The cold pool was azimuthally divided into 9 sections of which two channels containing DOTE, 4 channels containing IHX, 3 channels containing a primary pump.

4. Transient Simulation Results

4.1 Results using the 1-D nodalization

At 100 seconds, one secondary pump (PS1) was tripped and 5.5 seconds later a control rod is inserted into the core while another secondary pump speed starts to decrease from 540 rpm, which caused the sodium temperature to be increased. The speed of PS1 at 114.5 seconds was maintained at 100 rpm and at 147.5 seconds was scrammed due to the core outlet temperature increase. The speed of PS3 at 154.5 seconds was maintained at 110 rpm. Fig. 2 compares the temperatures between the calculation result and the test data in the cold pool. After the mass flow in the secondary side was reduced the IHX outlet temperature reached a maximum 436 ℃ in the test, however, the calculated temperature was 491 ℃.

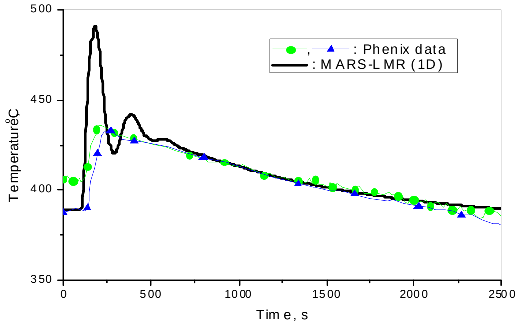

Fig. 2 Cold pool temperature using 1-D

This was caused by a 1-D modeling for the cold pool. At the test, hot sodium is dumped into the cold pool below IHX, and the sodium was mixed with the sodium of the azimuthally other region and thus the pump takes the colder sodium compared to the discharged sodium from the IHX and feeds it into the core inlet plenum. Also, the location for the cold pool temperature of the test data is the below DOTE which there are no flow like IHX outlet. So the temperature below DOTE might be slowly increased by mixing with a neighbor hot sodium below of IHX outlet.

4.2 Results using cold-pool multi-D nodalization

The analysis using the cold pool multi-D nodalization provides better results than the case of the 1-D modeling. The cold pool temperatures are different along with the azimuthal sections. Fig. 3 compares the cold pool sodium temperatures below DOTE. We can see that the maximum temperature nearly approaches to the test data.

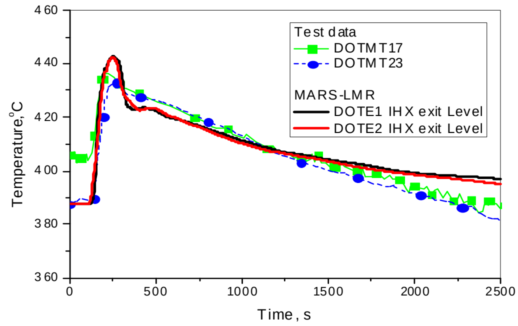

Fig. 3 Cold pool temperature using cold pool 2-D

3.3 Results using multi-D nodalization for both pools

The best results were obtained from a multi-D modeling for the hot and cold pools. Fig. 4 shows the cold pool temperatures below DOTE calculated by the MARS-LMR code compared with the test data. The maximum temperature is nearly the same as the test data. The results suggest that the hot and cold pools should be multi-dimensionally modeled.

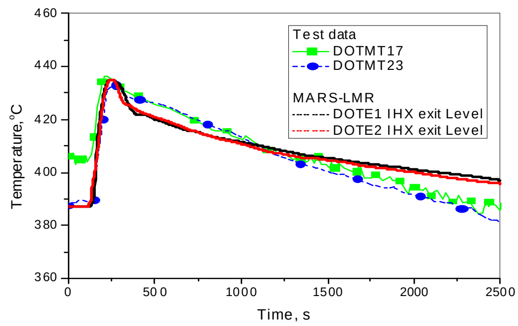

Fig. 4 Cold pool temperature using both pools multi-D

5. Conclusion

Asymmetric test of Phenix plant has been simulated with the MARS-LMR code and the influence of 1-D and multi-D modelings for the hot pool and cold pool was evaluated. In a one dimensional modeling the unrealistic temperature peak at the cold pool had occurred. The temperature peak disappeared in the cold pool multi-D modeling. A more detailed pool modeling for both pools provided a best prediction. Conclusively for a realistic transient simulation of the pool type sodium cooled fast reactor both the hot pool and the cold pool have to be modeled multi-dimensionally.

ACKNOWLEDGMENTS

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REFERENCES

[1] Kwi-Seok Ha et al., "Simulation of the EBR-II Loss-of -Flow tests using the MARS code", *Nuclear Technology*, Vol. 169, No. 2, 2010.