Evaluation of core modeling effect on transients for multi-flow zone design of SFR

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1. Introduction

Flow zoning concept is adapted for Sodium-cooled Fast reactor (SFR) core that normal flow rate of core assemblies are categorized with respect to their power level. For conventional PWRs, coolant flow of each fuel assemblies is assumed as uniform. So more simplified core modeling could be utilized to estimate important system safety parameters as well as the peak cladding temperature of PWR system with hot channel for high power assembly and averaged channel for other fuel assemblies.

SFR core is composed of different types of assemblies including fuel driver, reflector, blanket, control, safety drivers and other drivers. Modeling of different types of assemblies is inevitable in general. But modeling of core flow zones of with different channels needs a lot of effort and could be a challenge for system code modeling due to its limitation on the number of modeling components.

In this study, core modeling effect on SFR transient was investigated with flow-zone model and averaged inner core channel model to improve modeling efficiency and validation of simplified core model for EBR-II loss of flow transient case with the modified TRACE code for SFRs.

2. EBR-II (Experimental Breeder Reactor) and SHRT-17 test

Argonne National Laboratory's (ANL) EBR-II was a liquid metal reactor (LMR) with a sodium-bonded metallic fuel core that contributed very favorably to the reactor's negative reactivity feedback. On June 20, 1984, a severe loss-of flow test in the Shutdown Heat Removal Test (SHRT) series demonstrated the effectiveness of natural circulation in the EBR-II reactor. This test was SHRT-17 and at the beginning of the test the primary pumps were tripped at the same time as a full control rod insertion. [1]

2.1 EBR-II system description

The primary system is resided in the sodium tank pool. Two primary sodium pumps supply coolant into low pressure plena and high pressure plena. Outer core, composed of reflector and blanket drivers, receives coolant from the low pressure plena and inner core and extended core regions from the high pressure plena. Sodium temperature is increased through the core and flows into the intermediate heat exchanger (IHX) through upper plenum and Z-pipe. Finally hot sodium is cooled across the IHX and returns to the sodium pool as shown in Figure 1.

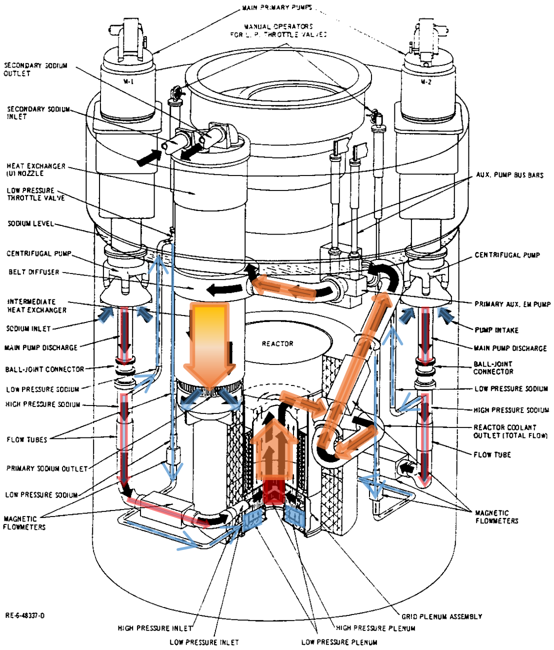

Fig. 1. EBR-II system layout and coolant flow

EBR-II core is composed of 637 sub-assemblies. 510 Reflector and Blanket sub-assemblies are located at the outer core region, and other 127 fueled driver, Control, Safety driver, Reflector and Steel rod drivers are located in the inner core region and extended core regions, those are regions that sodium is supplied from the high pressure plena.

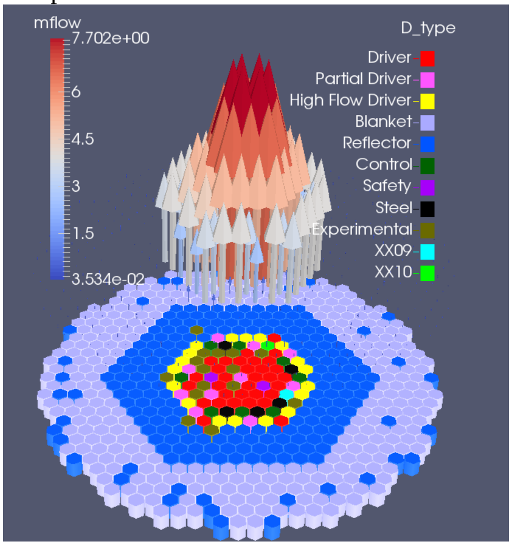

Fig. 2. EBR-II core configuration and flow distribution

As shown in Fig. 2, most of sodium injected into the core flows into the inner core region during normal operation.

2.2 SHRT-17 test description

The system was operated at full power (57.3 MWt) and flow (466.5kg/s) conditions before the test. With the primary coolant pump and the intermediate-loop pump trip, the reactor was scrammed simultaneously. The auxiliary EM pump installed in the Z-pipe was not activated in the test.

During the test, several measurements were made for Pump2 and instrumented drivers including XX09 and XX10 drivers in terms of sodium flow and sodium temperature.

Main feature of the test is balance between the decay heat and sodium flow driven by primary pumps coast down and natural circulation flow of the system. Fuel temperature is decided by this power and flow balance. For the system flow estimation, momentum loss in the core as well as pump coast-down characteristic is one of key parameters in the system analysis.

3. EBR-II system modeling

3.1 Modified TRACE code

For the safety analysis for SFRs, original version of TRACE code was modified, in which sodium enthalpy correlation was corrected with ANL's property and Simplified Cheng and Todreas (CTS) wire wrapped fuel bundle pressure drop correlation was also incorporated to the original TRACE5 Patch 2 code version.[3]

In this study, new version of modified TRACE code were used, based on the TRACE5 Patch 3 version and 1986's CTS correlation[4] was replaced with 2013's CTS correlation[5].

3.2 EBR-II system modeling

Base TRACE code modeling for EBR-II system is shown in Fig. 3. Reactor pool was modeled with VESSEL component. Two primary pumps and high and low pressure pipes were modeled with connection to high and low pressure plena each. Core was modeled with outer core (OC) and inner core (IC) group (g1~g10), XX09, XX10, bypass and non-fuel channel (Steel and Reflector drivers). These core channels were connected to the upper plenum volume and IHX through the z-pipe. Intermediate side of IHX was composed of downcomer pipe, lower and upper dome and IHX tubes. Their inlet and outlet were connected to the Fill and Break components to simulate the intermediate side boundary conditions of sodium flow and temperature.

Inner core region was modeled with 10 flow-zone channels based on the normal core flow categorization. Total 80 drivers are included in the 10 flow-zone channels. Hot driver, XX09 and XX10 and steel and reflector channels were model with separated channels for their own purpose. IC group1 (g1) and IC group4 (g4) were safety and control driver channels different from other fuel drivers.

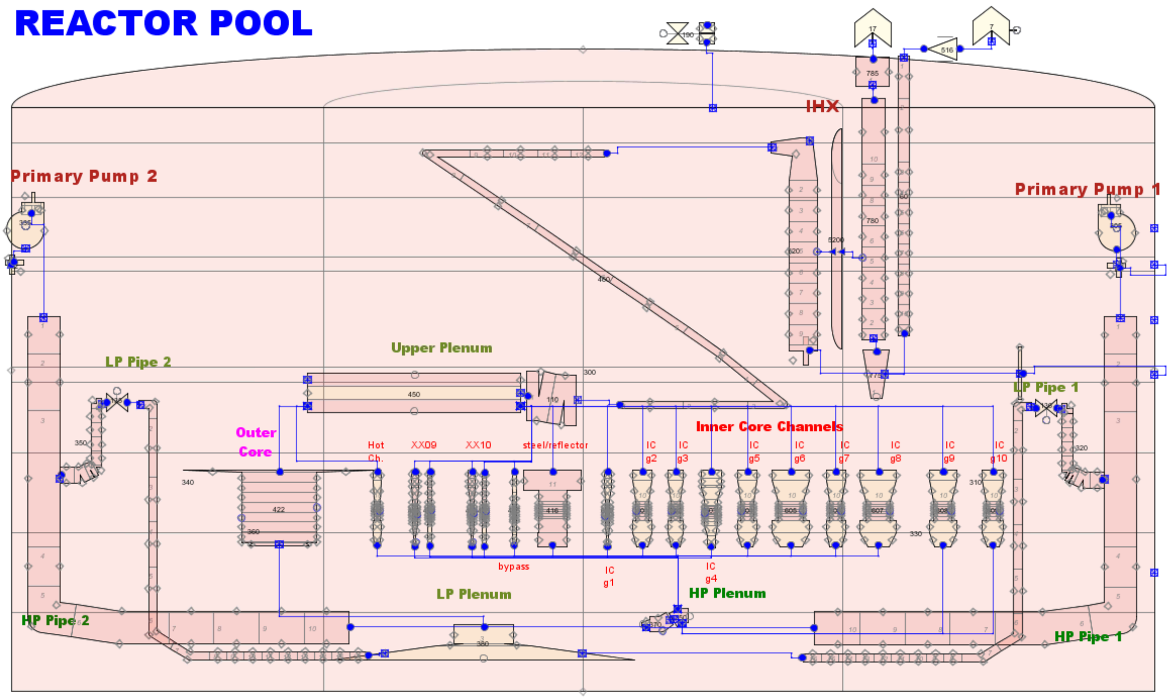

Fig. 3. TRACE code modeling for EBR-II

3.3 Inner core modeling cases

Based on the flow-zone channel modeling described at section 3.2, two core modeling cases were considered.

The first case (case 1) is averaged IC modeling case, same driver channels were modeled with single IC channel. IC g2-3 and g5-10 were merged with single IC channel considering flow area and volume, fuel heat structure and power.

The other case (case 2) is high flow driver based averaged IC case. Other inner core channels except the high flow group driver channel (IC g10) were modeled with a separated channel, and IC g2-3, g5-9 channels were merged with single averaged channel.

Due to the high flow of IC g10 channel, pressure drop of this channel is higher than other core channels. So the inlet orifice form loss of IC g10 channel is lowest among other core channels in the base case and case2. In modeling, based on the IC g10 inlet orifice form loss, other core channel's inlet orifice form losses were adjusted to achieve the desired channel sodium flows.

IC channel categorization and the normal flows are summarized in Table I for each cases.

Table I: Assembly number and flow distribution of inner core modeling cases

IC Groups	Base case		Case 1		Case 2	
	Assy. #	kg/s	Assy. #	kg/s	Assy. #	kg/s
g1(C)	1	0.65	1	0.65	1	0.65
g4(C,S)	8	26.55	4	26.55	4	26.55
g2	5	13.01	75	340.5	69	294.3
g3	3	9.40				
g5	5	17.63				
g6	19	74.10				
g7	5	22.02				
g8	18	91.80				
g9	10	66.34				
g10	6	46.20			6	46.20
Total	80	368.1	80	368.1	80	368.1

4. Case study for the loss of flow transient

4.1 Core modeling effect on sodium flow

Assessment results of the base case, case1 and 2 with respect to the core modeling method were compared in terms of flows for pump2, hot channel (HC) and XX09 instrumented driver channel as shown in fig. 4, 5, and 6.

The percentage of difference from the base case of the single IC channel model (case1) and the high flow channel plus averaged IC channel core model (case2) showed in lower part of each figures.

Before 50s, at which pump coast down is ended, case 1 predicted higher pump2, HC and XX09 flows than the base case with maximum flow difference of 5.9%, 1.8% and 2.3% each. For case 2, maximum difference from the base case were 0.9%, 0.6% and 0.7% each.

After the pumps coast-down, case 1 predicted about 2.5% higher HC and XX09 flows than the base case. But case 2 predicted 1.2% higher HC and XX09 flows than the base case around 75s, the flow difference was decreased below 0.5% after 100s.

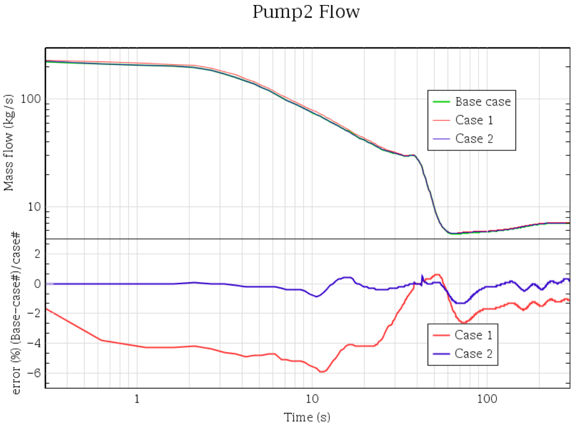

Fig. 4. Pump2 flow comparison for core modeling cases

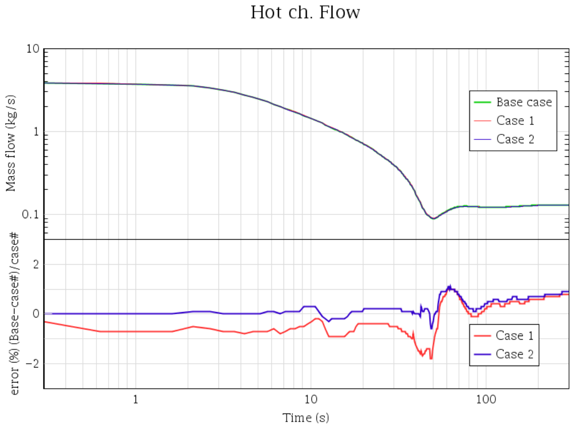

Fig. 5. Hot channel flow comparison for core modeling cases

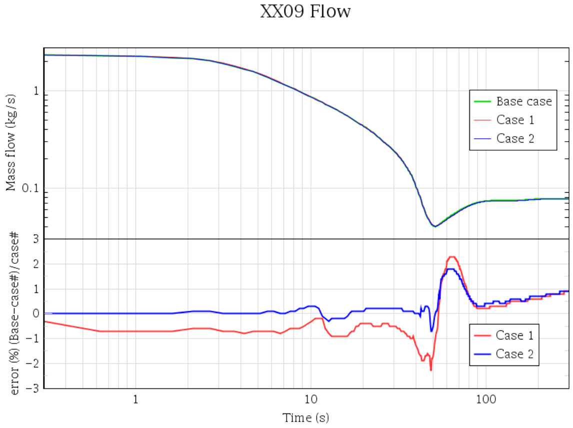

Fig.6. XX09 channel flow comparison for core modeling cases

4.2 Core modeling effect on channel outlet temperature

Hot channel and XX09 instrumented driver channel outlet temperature estimations of case 1 and 2 were also compared to the base case in fig. 7 and 8.

High channel flow estimation of the case 1, as addressed in section 4.1, resulted in low channel outlet coolant temperature estimation for HC and XX09 as shown in fig. 7 and 8. Maximum temperature difference between the base case and case1 were 1.6 K and 1.1K for HC and XX09 each before the outlet coolant temperature peak is occurred. For the case 2, HC outlet temperature difference from the base case were below 0.2 K before 57s and 1.3K higher temperature was estimated at 74.7s then 0.5 K lower temperature was estimated after 100s.

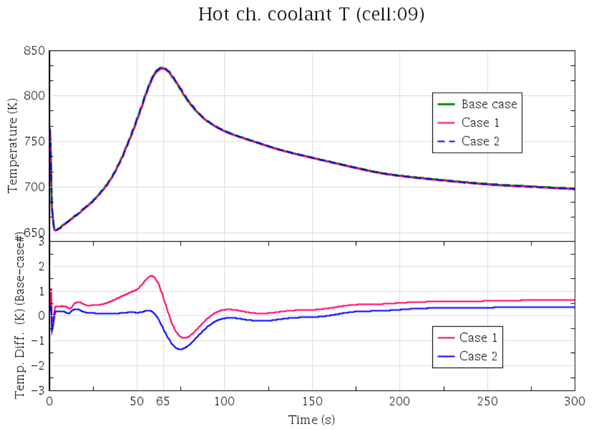

Fig. 7. Hot channel outlet coolant temperature comparison for core modeling cases

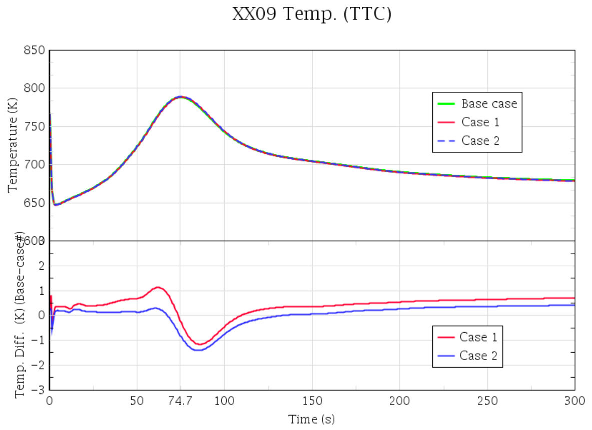

Fig. 8. XX09 driver outlet coolant temperature comparison for core modeling cases

Channel outlet temperature peaks were estimated at 65s and 74.7s for HC and XX09 each. The case 1 estimated 0.7K lower peak temperature and the case 2 0.5K higher peak temperature than the base case for HC. For XX09, case 1 and 2 estimated 0.2K and 0.8K higher temperatures respectively.

In terms of peak temperature estimation, the difference of the temperature of both inner core modeling cases were under 1K. Comparing between case 1 and 2, the case 2 was more similar to the base case for flow and channel temperature response.

5. Conclusions

Core modeling effect on the loss flow transient was analyzed with flow-zoned channel model, single averaged inner core model and highest flow channel with averaged inner core channel model for EBR-II SHRT-17 test core.

Case study showed that estimations of transient pump and channel flow as well as channel outlet temperatures were similar for all cases macroscopically. Comparing the result of the base case (flow-zone channel inner core model) and the case 2 (highest flow channel considered averaged inner core channel model), flow and channel outlet temperature response were closer than the case1 (single averaged inner core model).

Therefore, modeling of different normal flow channels composed of same type of wire-wrapped assemblies with a single channel is possible as long as the highest flow assembly is modeled with independent channel for modeling of SFR's flow-zoned core.

ACKNOWLEDGEMENTS

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