A study on a MATRA-LMR-FB prediction capability with an EBR-II natural circulation test

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1. Introduction

MATRA-LMR-FB is a key sub-channel analysis code for PGSFR (Prototype Generation IV Sodium-cooled Fast Reactor) design. Most of its verification efforts have been devoted to local sub-channel blockages, and most of the former studies were shifted to the analysis of 19-pin bundle subassemblies [1,2]. There always remained a question how to extend the result of such 19-pin analysis results to subassemblies with a full pin numbers. Other aspects such as radial temperature distribution in a subassembly, limitation of an inlet flow magnitude, and transient prediction capability were relatively overlooked. So far the MATRA-LMR-FB has been applied to a 37-pin subassembly with a wire-wrap spacer at most. MATRA-LMR-FB was assessed using KNS 161-pin bundle in the verification [3]. Although it might be successful to earn some insight of the eligibility of general sub-channel analysis models in MATRA-LMR-FB from the assessment, meaningful results on its capability for the wire-wrapped pin bundle could not be obtained because the KNS bundle had a grid spacer. Therefore, a subassembly containing more than 37 pins with a wire-wrap spacer was desirable to demonstrate predictability of the code. In this regard, a 61-pin test subassembly (XX09) placed in EBR-II (Experimental Breeder Reactor II) core was analyzed to demonstrate its extensive applicability in the present study.

Power operation of the EBR-II was begun by Argonne National Lab. (ANL) in 1964. Rated thermal power was 62.5 MW with rated primary sodium at 485 kg/s. The initial purpose of the operation was only demonstration of the feasibility of a closed fuel cycle that required the addition of only Uranium-238 to fuel the breeding process and allow for sustained operation until it was shut down in 1994. The shutdown Heat Removal Test (SHRT) program was carried out in EBR-II between 1984 and 1986 in order to provide not only test data for validation of computer codes but also demonstration of passive reactor shutdown and decay heat removal in response of protected and unprotected transients [4].

Figure 1 illustrates the primary tank in EBR-II. All major primary system components were submerged in the primary tank, which contained approximately 340 m^3 of liquid sodium at 371 ^oC. Hot sodium heated up though subassemblies exited into a common upper plenum where it mixed before passing through the outlet pipe into the intermediate heat exchanger (IHX). The pipe feeding sodium to the IHX is referred to as the 'Z-pipe'. Sodium then exited the IHX back into the primary sodium tank before entering the primary sodium pumps again.

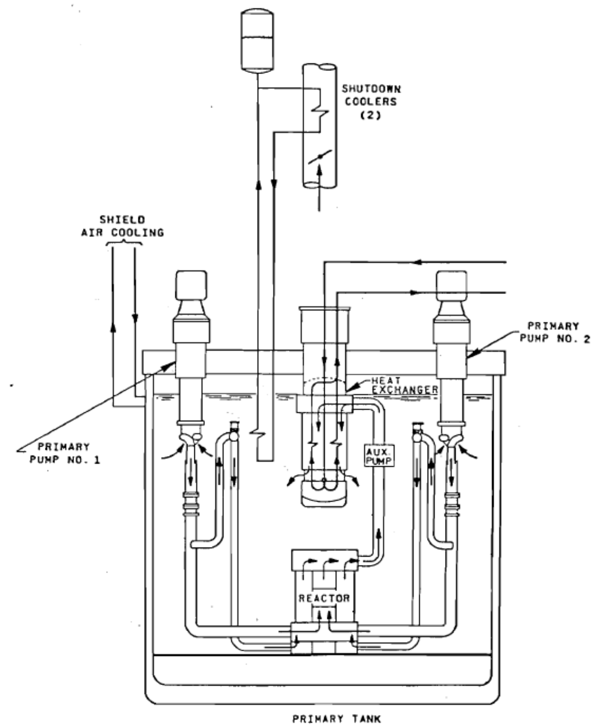

Fig. 1. EBR-II Primary Tank Sodium Flow Paths [4]

The core in the reactor vessel accommodated 637 hexagonal subassemblies. Two positions in the central core in Row 5 contained the instrumented subassemblies, XX09 and XX10. Figure 2 schematically illustrates the pin arrangement and the instrument loading for the XX09 subassembly.

2. Analysis

2.1 EBR-II SHRT-17 test

The SHRT-17 test data were compared with the MATRA-LMR-FB calculation results for the steady state in this study. The SHRT-17 was a loss of flow test and was performed on June 20, 1984 for demonstration of the effectiveness of natural circulation cooling characteristics. The transient was initiated by a trip of the primary and intermediate pumps. The reactor was also simultaneously scrammed to simulate a protected loss-of-flow accident. In addition, the primary system auxiliary coolant pump that normally had an emergency battery power supply was turned off. As the test

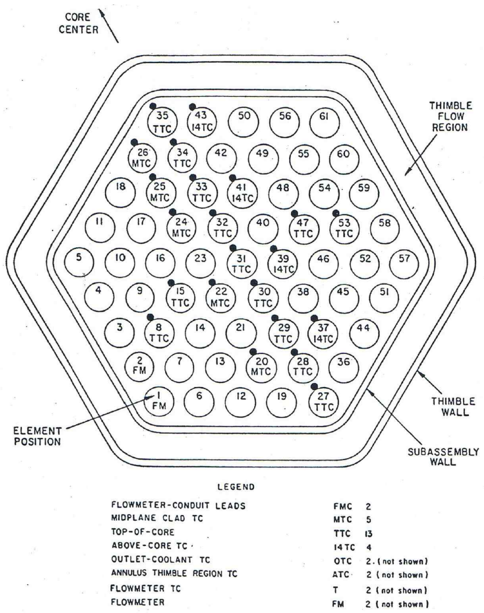

Fig. 2. Pin arrangement and instrument loading in XX09 Subassembly [4]

continued, the reactor decay power decreased due to fission product decay. After the start of the test, no automatic or operator action took place until the test had concluded. Figure 2 displays the cross-section of the XX09 subassembly along with the measurement positions, and elements #1, 2 in the figure indicate the no heat generating pins.

The initial core flow rate for the SHRT-17 test was 8,500 gpm, the average core inlet temperature at the start of the test was 664.8 ^{o}F. The initial pressure at the discharge of primary sodium pump #2 was 41.9 psig. At the outlet of the core, the initial upper plenum pressure was 6.36 psig. Figure 3 shows the power and flow variations during the test transient.

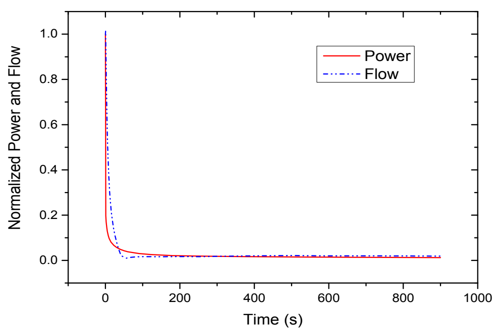

Fig. 3. Power and flow transient in the test

2.2 The MATRA-LMR-FB input

In the MATRA-LMR-FB input, total active length of the sub-channels (13.50 inches) was divided axially into 14 equally sized nodes. A preliminary study on node sizes was conducted to find a suitable size of the node, and a node size in neighborhood of 1-inch yielded stable solutions. The axial heat flux distribution was given in the active region with calibrated power distribution from the test result. Table 1 summaries key MATRA-LMR-FB input parameters for the XX09 subassembly in this test. The thimble flow is not modeled at present, because its information is not quite in detail and it would not be a critical factor in the steady-state analysis. The sub-channel numbers were assigned as shown in Fig. 4 for the MATRA-LMR-FB calculation. Since there were two pins with no heat generation (pin #54, 55 in Fig. 4), the total subassembly power was equally allocated to the rest of 59 pins for the compensation.

Table 1. Key input parameters for the SHRT-17 test

Parameters	**Unit**	**Inputs**
Number of pins		61
Number of unheated pins		2
Diameter of pin	inch	0.1736
Pin pitch	inch	0.2224
P/D		1.281
Total length of pin	inch	24.09
Active length of pin	inch	13.50
Wire-wrap pitch	inch	6.0
Diameter of spacer wire	inch	0.0488
Inner Flat-to-flat length	inch	1.827
Flow rates	kg/s	2.377
Power inputs	MW	0.393
Inlet temperature	^{o}F (^{o}C)	664.8 (351.6)

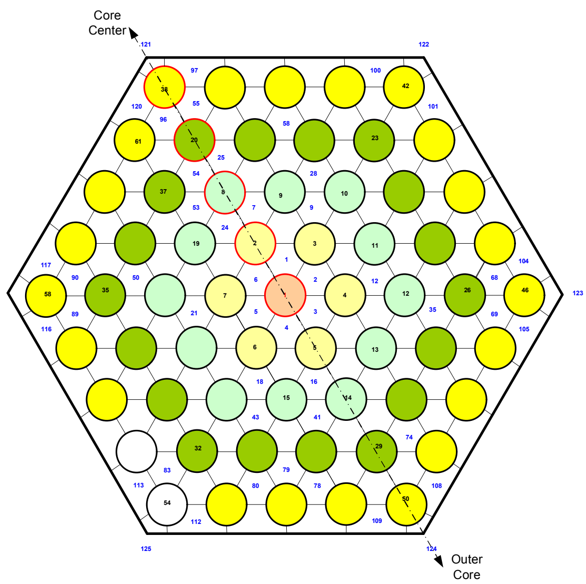

Fig. 4. Cross-sectional configuration of XX09 subassembly for the MATRA-LMR-FB calculation

2.3 Results

The MATRA-LMR-FB calculation was carried out using the aforementioned inputs for 5 s to achieve the steady state. It was sure that MATRA-LMR-FB successfully reached the steady state within the time period. Figure 5 represents a comparison of the temperature distribution along the sub-channels where the temperature measurements were made as indicated with 'HTC' in Fig. 2. While coolant temperatures were over-predicted in the sub-channel close to the core center, the temperatures in the sub-channels opposite to the core center were considerably under-predicted. Such discrepancies seemed to come from either miscalculation of sub-channel flow distribution or inconsistency of the radial pin power distribution which was unknown, or both. As there was no datum to be compared for these parameters, a sensitivity study must be helpful to identify the source of the discrepancy more realistically. Nevertheless, overall trend of the temperature distribution seemed to be reasonable.

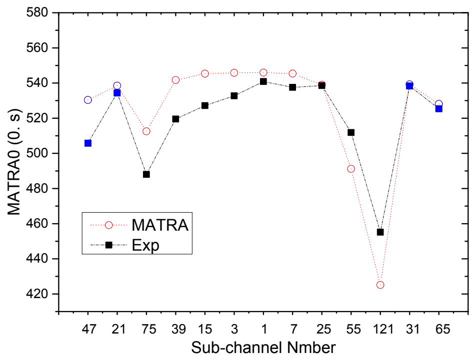

Fig. 5. Comparison of sub-channel temperature (HTC) distribution

Fig. 6 compares 5 data points of the cladding temperatures at axial mid-plane, which are indicated with 'MTC' in Fig. 2. It also shows some discrepancy for a pin positioned near the outer core (#30). It was conjectured that radial flow distribution associated with cross flow might be a main factor to affect the result. It is also elucidated with sensitivity studies later on.

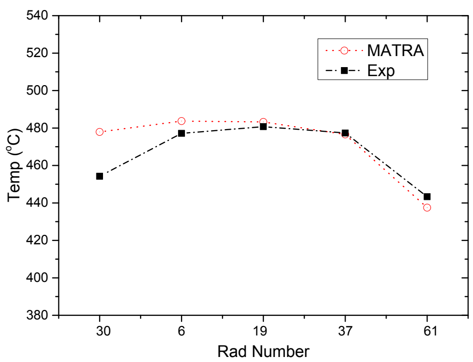

Fig. 6. Comparison of cladding temperature (MTC) distribution

3. Conclusion

The EBR-II SHRT-17 test data were used to demonstrate the prediction capability of MATRA-LMR-FB for the steady state temperature distributions. As a result, the code could predict a reasonable trend but there were some discrepancies in the prediction of temperature magnitude. It is not possible to catch the sources of those discrepancies at the present time, because there were not corresponding test data to be compared. Therefore, some sensitivity studies must be followed to identify whether the discrepancies resulted from either input uncertainty or a limit of the code capability.

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