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Analysis of Local Recirculation Flow Under Sub-Channel Blockage Accident

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1. Introduction

A sub-channel blockage may be caused by an ingression of damaged fuel debris or foreign obstacles into a core fuel subassembly for a liquid metal reactor (LMR) due to its geometrical compactness of the core design. Local coolant temperature in the subassembly could be affected sensitively by coolant recirculation above the blockage under the accident, because it leads to flow stagnation while delaying the active mixing. Therefore, the maximum temperature in the subassembly relies largely on a recirculation flow pattern. The present manuscript elucidates the recirculation flow for different blockage sizes and positions in the subassembly. This study helps one understand a difference for the maximum temperature between the blockage cases.

2. Analysis

The MATRA-LMR/FB code [1] has been used to analyze the breakeven core design of KALIMER-150 [2]. The three blockage sizes and three radial positions for each size were examined in this study. The blockage sizes were represented with 6, 24, and 54 sub-channels blockages, and the radial positions were located in the center, midway between the center and duct wall, and the edge of the subassembly. The hot assembly was chosen for conservative analysis. The subassembly consists of 271 fuel rods, and the sub-channel was divided axially into 117 nodes (3.02 cm/node) for the input. [3]

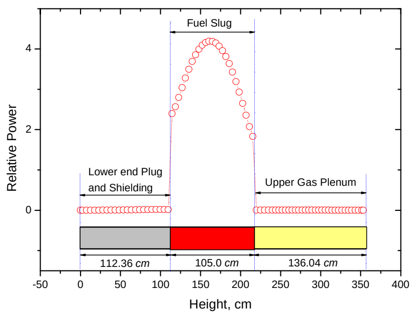

Fig. 1 Axial power distribution for MATRA inputs

Figure 1 depicts the axial distribution of the relative heat generation in the fuel rod for input. Its radial distribution was assumed as uniform. A fuel slug was plugged inside a cladding tube between 112.36 *cm* and 217.36 *cm* from the channel inlet. The node number for its beginning corresponds to 38, while its end falls into the node number of 72. The maximum heat generation emerged at 160.7 *cm* above the inlet (the node number 54), and thereby the blockage was assumed to happen in this node for conservatism.

Maximum temperature was predicted near the end of the fuel slug (the node number 73). It would also be estimated at the top for a few cases including a blockage absent case. Meanwhile, the sub-channel number for its occurrence was usually predicted in one of the blocked sub-channels. This meant that the flow in the downstream of the blockage would sustain itself without mixing actively with its surroundings within a certain distance as shown in Fig. 2. The flow, however, mixed almost uniformly near the channel outlet. The blockage played an obstacle causing a local flow perturbation with a wake in the downstream.

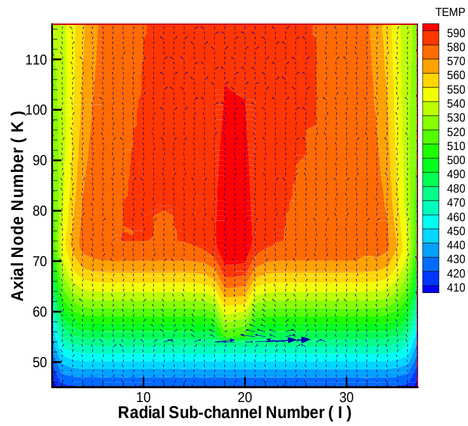

Fig. 2 Temp. and flow profiles for the 6-centeral blockage

The axial flow in the node number of 55, which was the upper one next to the blockage, is shown in Fig. 3. Although the flow in this node would be low, it still had a very small positive value right above the blockage. Therefore, recirculation was not initiated. A similar behavior was obtained for the other blockage positions.

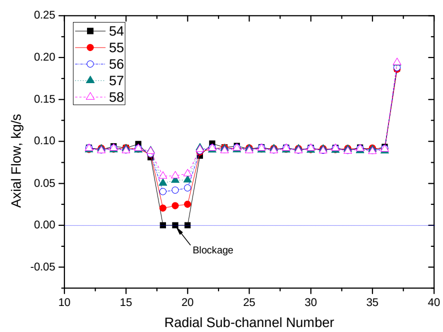

Fig. 4 Axial flow distribution for the 6-centeral blockage

On the other hand, the recirculation was recognized around a short range of the blockage downstream for blockages larger than the 6 channels. A negative flow was predicted in a few axial nodes above the blockage as seen in Fig. 4 and 5. No more than 3 nodes in the wake region had a reverse flow in any case. As the recirculation occupied a larger region, a higher maximum temperature was calculated. The main reason for this was attributed to a prolonged coolant heating time, due to the recirculation, before the coolant reached an axial position in the downstream.

The edge 54 channels blockage shown in Fig. 4 exhibits somewhat a distorted axial flow profile. The flow in the node number 55 came out lower than that in the node number 56, which is the upper node of 55. It is not an ordinary behavior when it is compared with the other cases such as the result in Fig. 5.

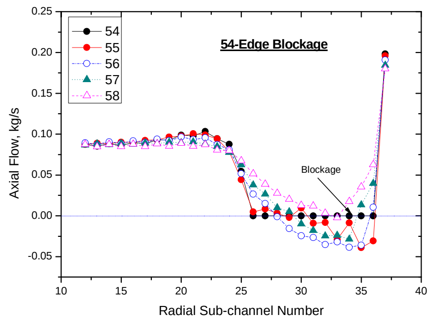

Fig. 4 Axial flow distribution for the 54-edge blockage

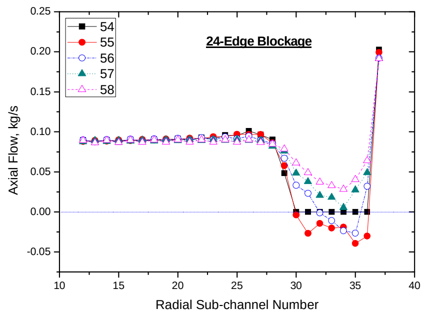

Fig. 5 Axial flow distribution for the 24-edge blockage

It was considered that the relatively stronger swirling flow induced by the duct wall, swept the downward recirculating coolant toward the subassembly center for the case of the 54 channels blockage as illustrated in Fig. 6. Consequently, its traveling time was so long that it could reach the maximum temperature in the axial node just above the blockage, i.e. the node number 55, even before getting out of the blockage wake radially. The sub-channel number where it occurred was shifted toward the center, compared with the case of the 24 edge blockage (Fig. 7). For the case of the 24 edge blockage, however, the axial position for the maximum temperature was the node number 73 like most of the other cases. The maximum temperature for all the blockage cases was always biased toward the center by the influence of the swirling flow directed from the duct wall to the center.

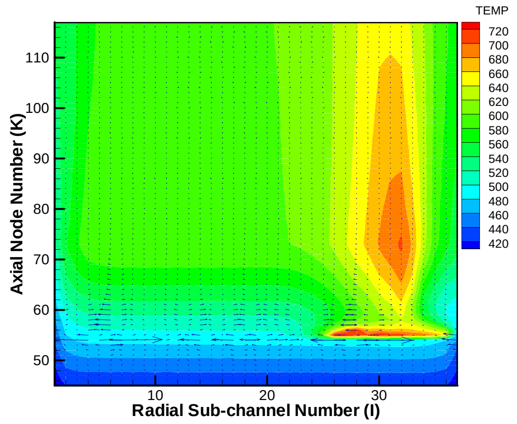

Fig. 6 Temp. and flow profiles for the 54 edge blockage

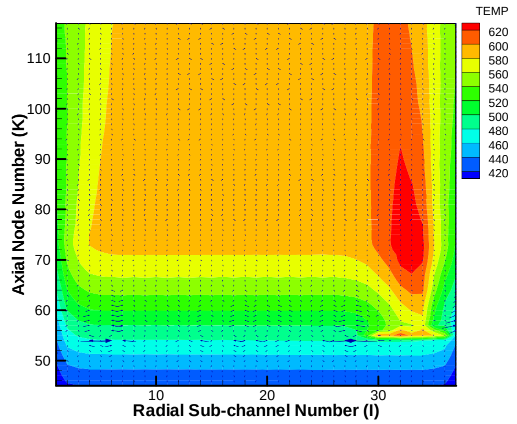

Fig. 7 Temp. and flow profiles for the 24 edge blockage

3. Conclusions

The maximum temperature for most blockage cases was influenced by the recirculation above the blockage as well as the swirling flow induced at the duct wall. Generally, the larger blockage area led to a higher maximum temperature due to an extension of the recirculation region. The extension was because the recirculation provided a longer time for coolant heat-up with less mixing. The blockage position was another factor affecting the maximum temperature due to the swirling flow. For a small blockage like 6 channels blockage, however, a reverse axial flow wasn't predicted in this analysis.

REFERENCES

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