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Complete Flow Blockage of a Fuel Channel for Research Reactor

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1. Introduction

A flow blockage of fuel channels can be postulated by a foreign object blocking cooling channels of fuels. Since a research reactor with plate type fuel has isolated fuel channels, a complete flow blockage of one fuel channel can cause a failure of adjacent fuel plates by the loss of cooling capability. Although research reactor systems are designed to prevent foreign materials from entering into the core, partial flow blockage accidents and following fuel failures are reported in some old research reactors [1,2].

In this report, an analysis of complete flow blockage accident is presented for a 15MW pool-type research reactor with plate type fuels. The CHF correlation suitable for narrow rectangular channels are implemented in RELAP5/MOD3.3 code for the analyses, and the behavior of fuel temperatures and MCHFR(minimum critical heat flux ratio) are compared between the original and modified codes.

2. Analysis Methods

Figure 1 shows the nodalization of fuel channels for flow blockage of the reactor. The fuel channels are divided into three individual hot channels (P240-P244) and one average channel (P250) which represents the other channels except the hot channels. The four hot fuel plates (H240-H245) generates higher heat flux than that of average fuel plate (H250) considering the radial peaking factor and the engineering hot channel factor which related to the fuel tolerances and calculation uncertainties. For conservative analysis, the flow rate of hot channels is set to be less than that of average channel.

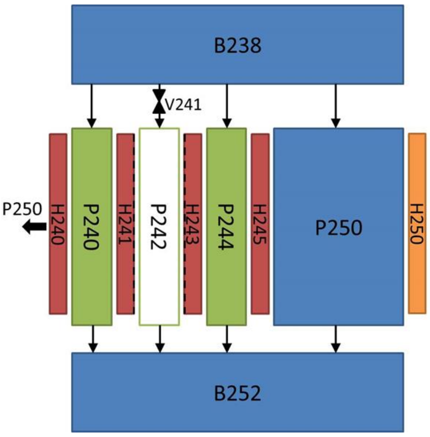

Fig. 1 Modeling of fuel channels of for complete flow blockage analysis

The complete flow blockage of one fuel channel is modeled such that the valve connected at the inlet of a hot fuel channel is closed instantaneously, and the fuel surfaces toward the closed channel becomes insulated with the accident initiation. A melting of fuel is modeled by setting the specific heat of the fuel, cladding, and corrosion layers to be infinite above the melting point of the fuel (570°C), which prevents the unrealistic temperature rise of the fuel.

Sudo-Kaminaga CHF correlations for rectangular channels are implemented into RELAP5/MOD3.3 for the analyses, since the original RELAP5/MOD3.3 does not equip the proper CHF correlation for the narrow rectangular channels with the current reactor conditions [3]. A new subroutine of Sudo-Kaminaga correlations is written and then is set to alternate the existing AECL CHF table. The uncertainty of Sudo-Kaminaga CHF correlation (33%) is conservatively reflected in the CHF calculation.

The complete flow blockage is analyzed with the original/modified RELAP5/MOD3.3 for comparison. For the original RELAP5/MOD3.3, the CHFRs are calculated either by the code itself, or separately at the outside of code by Sudo-Kaminaga correlations with the properties estimated from the code. The maximum temperature is also estimated by both codes, to examine the integrity of fuel adjacent the blocked channel.

The fuel is considered maintaining the integrity when both the maximum fuel temperature is less than the blistering temperature of 400°C, and the minimum CHFR is higher than the safe criterion, 1.

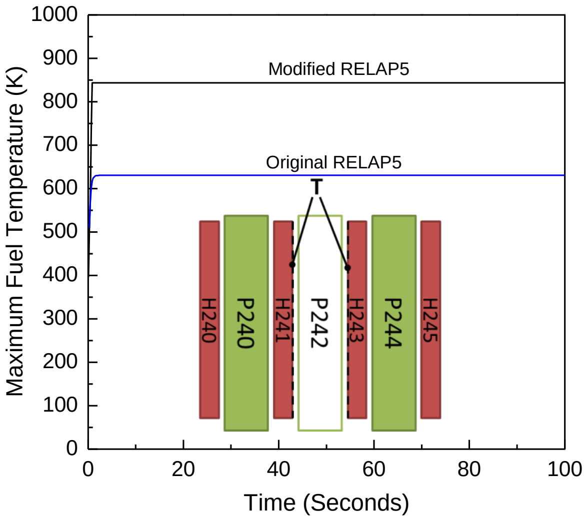

Fig. 2 Maximum fuel temperatures adjacent to the blocked channel.

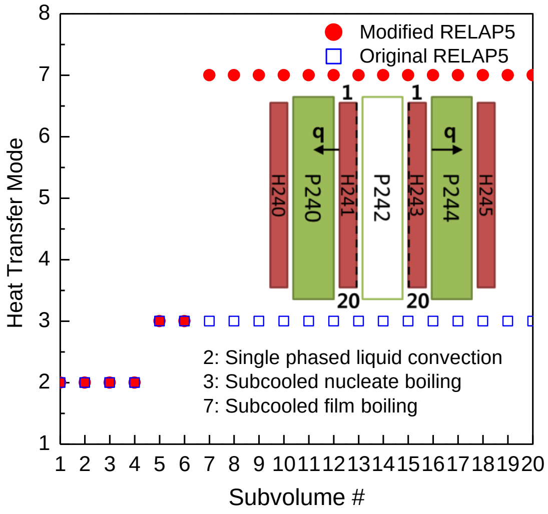

Fig. 3 Heat transfer regime of the fuel adjacent to the blocked channel

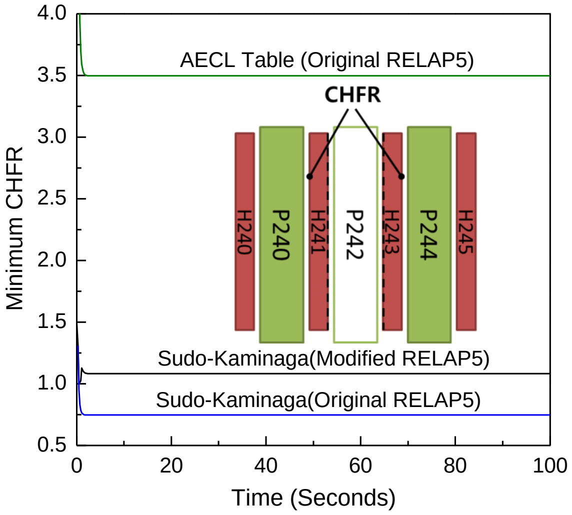

Fig. 4 MCHFR at the fuel adjacent to the blocked channel

3. Results

Figure 2 shows the maximum fuel temperatures adjacent to the blocked channel. The modified RELAP5/MOD3.3 predicts the maximum fuel temperature to reach the melting point instantaneously with the accident initiation, whereas the original RELAP5/MOD3.3 predicts the temperature remaining below the melting points. The discrepancy is originated from different flow regime map associated with the calculated CHFs by the codes.

Figure 3 shows the heat transfer mode of subvolumes estimated from original and modified RELAP/MOD3.3. At the subvolumes below volume 7, the modified RELAP5/MOD3.3 determines the heat transfer regime to be subcooled film boiling. Once the heat flux from the fuel exceeds the CHF, a departure from nucleate boiling occurs and the maximum heat transfer coefficient from the fuel surface starts to decrease. Then the heat generated from the fuel does not transferred to the coolant sufficiently, causing the damage on the fuel. However, the heat transfer regime of original RELAP5/ MOD3.3 remains at the subcooled nucleate boiling, since the calculated CHF by the code is much higher than that by modified RELAP5/MOD3.3

Figure 4 shows the MCHFR at the fuel adjacent to the blocked channel. Since the original RELAP5 /MOD3.3 estimates the CHF based on AECL Table, the CHFR from the code remains far above the safety criterion for fuel failure. When the CHFR is calculated from the Sudo-Kaminaga correlation with the variables calculated from the original RELAP5/MOD3.3, the CHFR drops under 1. Since the CHF is the maximum possible heat flux from the heated surface, the heat flux higher than the CHF is physically unrealistic. This phenomena is caused by the discrepancy between the CHF calculated in the code and that used for CHFR calculation outside the code. On the contrary, the CHFR calculated from the modified RELAP5/MOD3.3 is kept above 1 since the maximum heat flux from the surface cannot exceed the CHF calculated in the code.

From the MCHFR and the maximum fuel temperatures from modified RELAP5/MOD3.3, the fuel is considered to be damaged or melted, whereas the fuel integrity seems ensured by original RELAP5/MOD3.3. The results shows that the proper CHF correlation need to be implemented in the system code when calculating the events to exceed the CHF.

4. Conclusion

The complete flow blockage of fuel channel for research reactor is analyzed using original and modified RELAP5/MOD3.3 and the results are compared each other. The Sudo-Kaminaga CHF correlation is implemented into RELAP5/MOD3.3 for analyzing the behavior of fuel adjacent to the blocked channel.

The fuel surface experience different heat transfer regime in the results from original and modified RELAP5/MOD3.3. By the discrepancy in heat transfer mode of two cases, a fuel melting is expected by the modified RELAP5/MOD3.3, whereas the fuel integrity is ensured by the original code.

Acknowledgement

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