An Assessment of Offtake Effect on Horizontal Stratified Flow with Arbitrary-Angled Branches in CANDU Reactors

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I. Introduction

Safety analysis of a reactor inlet header 35% break with a loss of class IV power for Wolsong Unit 2 was performed using improved RELAP/CANDU code. RELAP/CANDU [1] is a thermal-hydraulic system code for CANDU reactors developed on the basis of RELAP5/MOD3 in such a way to modify inside model for simulating the thermal-hydraulic characteristics of horizontal type reactors. In this study, among the modified models, the effects of new offtake model [2] at arbitrary-angled branch pipes were investigated for the CANDU reactors. The simulation results of the RELAP/CANDU code were compared with those of the CATHENA code used in Wolsong Unit 2, 3, 4 FSAR [3]. From the results of the verification study, it is recognized that the new offtake models made an effect on the mass flow rates from header to feeder pipes penetrating the fuel channels and the temperatures of the fuel cladding significantly.

II. Thermal-hydraulic Modeling

Heat transport system (HTS) consists of two closed loops to reduce the coolant leakage in case of LOCA and the close channels in each loop has the opposite flow direction. The fuel channels are modeled with three averaged channels for channel 1, 2, and 3 and each channel contains 95 calandria tubes. But Channel 4 is divided into 4 groups as shown in Figure 1. Group 1 is an averaged channel having 92 calandria tubes and the entrainment option is inactive at the junction between header and feeder pipes. Group 2, 3 and 4 are single channels having the angles of feeder pipes (0°, -36° and -72°) respectively and the entrainment option is active or inactive according to whether or not for the use of offtake model at the junction between header and feeder pipes.

If there are N pipes with same area, length and volume, they can be averaged to one pipe in RELAP/CANDU. Then the relations between individual pipe and averaged pipe are as follows:

$$A_{avg} = A_{individual} \times N \tag{1}$$

$$V_{avg} = V_{individual} \times N \tag{2}$$

$$L_{avg} = L_{individual} \tag{3}$$

In this study, the areas of feeder pipes in channel 1, 2 and 3 are 95 times as large as the area of one feeder pipe. Regarding offtake phenomena, the average channel can not predict the realistic offtake phenomena due to these area restrictions. So for the critical path (channel 4) of the broken loop, 92 fuel channels are averaged to group 1, and the other 3 fuel channels are modeled to group 2 (0°), 3 (-36°) and 4 (-72°) with single channel to represent the offtake phenomena properly.

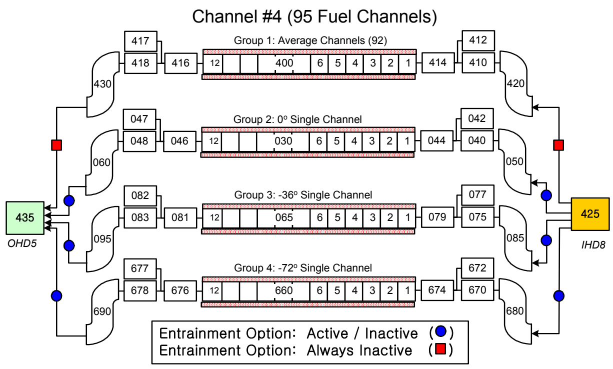

Figure 1. 4 group nodalization model of channel 4 according to the angles between feeder pipes and headers with and without offtake option

III. Numerical Simulation of RIH35% Break with Loss of Class IV Power

3.1 Initial Steady-State Conditions

The initial reactor power is assumed to be at 103% to account for bulk reactor power uncertainties. The effects of reactor aging are considered by modeling the initial conditions with about 4.8% flow quality in the reactor outlet headers. The initial thermal-hydraulic properties were well agreed with the design values for 103% power operation condition in the Wolsong Unit 2 Final Safety Analysis Report.

3.2 Transient Simulation

The results of transient simulation of RIH 35% break with loss of class IV power using improved RELAP/CANDU were compared with those of CATHENA used in Wolsong Unit 2 FASR to validate the capability of RELAP/CANDU code. Though there were some differences in the ECCS and turbine system, the whole trend of RIH 35% break with loss of class IV power using RELAP/CANDU was well agreed with that using CATHENA.

The focus of this study is that how much the offtake effects between header and feeder pipes affect the fuel cladding temperatures and mass flow rates. Thus in the calculation with RELAP/CANDU code, two cases were performed to investigate the effects of the offtake models at arbitrary-angled branch pipes. One is a case that offtake options are inactive ("No-Offtake") at the junctions between feeder pipes and headers, and the other is a case that offtake options are active ("Offtake") at the junctions between feeder pipes and headers with improved offtake models.

In Figure 2, there are large differences in the fuel cladding temperatures at the 7th node in the critical path (channel 4) between the case of "No-Offtake" and that of "Offtake" in RELAP/CANDU code. In the case of offtake option inactive, the fuel cladding temperatures in the group 1, 2, 3 and 4 are similar mutually. But in the case of offtake option active, there are large differences in the fuel cladding temperatures at each group respectively. It is because that the amount of entrained vapor/liquid (void fraction) is different at the junctions between feeder pipes and headers at each group as shown in Figure 3. In the case of offtake option active, the fuel cladding temperatures of group 2, 3 are higher than those of group 1, 4. It is because the void fraction of reactor inlet/outlet header is so large that there are small liquid entrainments at group 2 (0°) and 3 (-36°) but large liquid entrainments at group 4 (-72°) as shown in Figure 3.

For the results calculated by CATHENA code, channel 4 is a single average channel (95 fuel channels). The angle between inlet header and single average feeder pipe is -56.4° and that between outlet header and single average feeder pipe is -32.4°. The mass flow rate in channel 4 is negative at about 20~180sec, so it is reasonable that the fuel cladding temperatures of group 2 (0°) and 3 (-36°) using offtake models in RELAP/CANDU code are similar with that of channel 4 in CATHENA code (phase separation at -32.4° for negative flow direction) as shown in Figure 2.

There were considerable differences in the mass flow rates among group 2, 3 and 4 for the case of "Offtake" due to the amount of entrained vapor or liquid.

IV. Conclusion

The safety analysis on RIH 35% break with loss of class IV power for Wolsong Unit 2 was performed using improved RELAP/CANDU code to investigate the effects of offtake model on the real CANDU reactor.

Through the numerical simulation, we could know that the effects of offtake models at arbitrary-angled branch pipes are significant in the mass flow rates at the junctions between headers and feeder pipes and the fuel cladding temperatures. The results and methodology of this study will contribute to establish independent validation assessment technology and safety assessment system for the operating reactors.

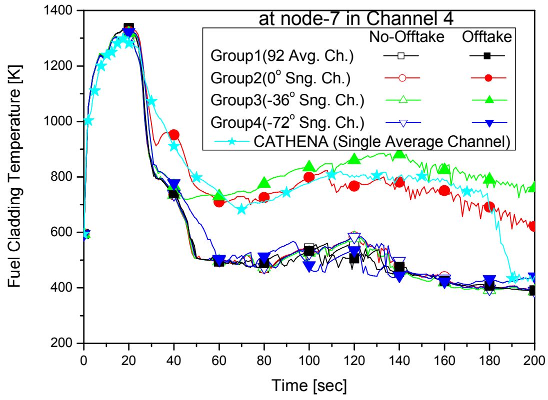

Figure 2. Fuel cladding temperatures at node-7 in channel 4 for each group

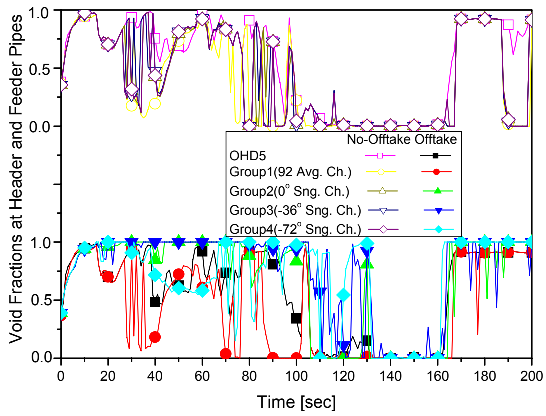

Figure 3. Void fractions at header and feeder pipes

References

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