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Fuel Channel Integrity Evaluation under SBO for CANDU-6

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ABSTRACT

After Fukushima accident, reassessment of the safety of Nuclear Power Plant (NPP) under multiple component failures initiated by internal and external events is now proceeding for the two oldest plants, Wolsong-1 and Kori-1. As one of the most severe accident, the station blackout (SBO) is assumed under the condition that all electric power including emergency power is not available for Wolsong-1 reactor. The fuel channel is the most important physical barrier preventing the release of radioactive material and pressure boundary of primary heat transport system (PHTS). In this analysis, the integrity of fuel channel is assessed through single channel analysis during this severe accident and whether the channel failure time can be predicted from circuit analysis without single channel analysis being assessed.

1. Introduction

As a part of Nuclear Safety and Security Commission (NSSC) project, "Development of Analysis Methodology for Beyond Design Basis Accident based on RD-310[1] for CANDU" has been studied. As a part of this study, the fuel channel behavior is evaluated under the event of the loss of heat sink(LOHS) accident like the Fukusima nuclear accident three years ago.

To have a better knowledge and estimation of channel behavior, the channel behavior has been simulated using single channel slave model in this study.

2. Analysis Method

2.1 Representative Channels

A single channel model is necessary for analyzing the behavior of each channel in the core for the purpose of a single-channel behavior analysis under the loss of heat removal. eight representative channels (A9, B10, G5, L3, O6, O6M, S10 and W10) are modeled based on their horizontal locations in the core and channel power in this analysis. The channel power and flow of eight representative channels are shown in Table Ⅰ. The channel condition in Table Ⅰ is for fresh core after retubing as the channel failure occurs earlier in fresh core than aged core[2].

Each fuel channel consists of 12 thermal hydraulic components of fuel bundle along the axial direction and both pressure tube(PT) and calandria tube(CT) are divided into 12 sectors along azimuth angle.

Table Ⅰ: Representative Channels

Channel	Steady Condition	
	Power (kW)	Flow (kg/s)
A09	3165	11.57
B10	4403	16.75
G05	5744	23.52
L03	5809	22.81
O06	6561	25.52
O6M	7300	24.65
S10	6330	26.93
W10	2986	12.45

The slave model is used for single channel model by using the header boundary conditions obtained from circuit analysis with multiple average channel group. The circuit model includes primary heat transport system (PHTS), secondary system and emergency core cooling systems and 380 fuel channels are modeled as multiple average channel group. CANDU-6 reactor consists of two PHTS loops and each loop has 2 core passes with 95 channels per core pass. 95 channels per core pass are represented by 7 average channel groups and each channel group represents average channel behavior of constituent 11~19 channels.

2.2 Channel model composition

Fuel channel analysis is performed using CATHENA[3] thermal hydraulic computer code to access the fuel channel behavior under SBO. The plant is assumed to be initially operated at 100%FP.

The radiation model is included to calculate the heat exchange among fuel elements, PT and CT due to thermal radiation. The fuel channel deformation model is also included for the prediction of ballooning or rupturing of PT. When PT balloons contact with CT, the heat is transferred to moderator surrounding CT. If the ballooning contact occurs, then the channel is assumed to be failed in this analysis. Thus, the moderator is not credible under this accident.

For the simulation of the accident, the event that all electric power including emergency power is not available is considered. It is assumed that the components and system structures to mitigate the consequences of the event are not operable and remains at failed condition. The operator action to reduce the effect of the accidents is also not considered and only the passive operating components are available. After the system behavior is estimated from circuit analysis under this accident, single channel analysis is performed using the header boundary conditions obtained from circuit analysis. The channel failure criteria is based on the first contact time of PT with CT or PT broken time, and it also means the damage of channel by the result of CATHENA computer code calculation.

Fig.1. is attached in order to understand the steps of calculation.

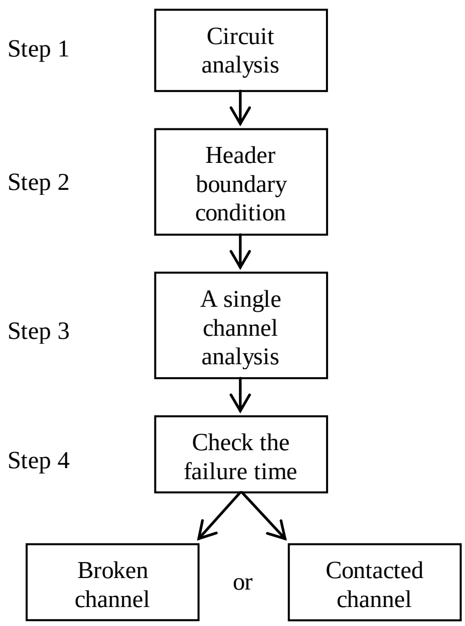

Fig.1. Steps of Calculation

3. Result

3.1. Result of circuit analysis

As all heat sink is assumed to be unavailable, the feed-water is not supplied to steam generator(SG) any more. After the inventories in SGs are depleted through passive operation of main steam safety valves (MSSVs), the heat transfer is not available and the temperature of fuel channel starts to increase[4].

The temperature behavior of fuel clad and is shown in Fig.2. and 3. As shown in these figures, the heat-up of fuel clad starts at about 5400 seconds and the heat-up of PT appears at about 1600 seconds later than the fuel clad and the trend is similar to other core passes.

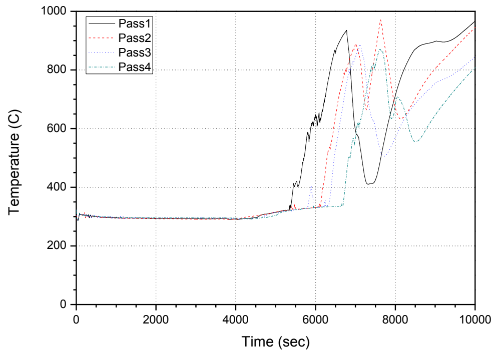

Fig.2. Maximum Temperature of fuel clad (circuit analysis)

3.2. Result of single channel analysis

From the temperature behavior assessment of 8 representative channels for core pass 1 through 4, the heat-up time of pass 1 is mostly faster than the other 3 passes. Representatively, the temperature behavior of fuel clad and PT for S10 channel of core pass 1 is shown in Fig.4. and the trends of other channels show almost the same trend as well. From CATHENA simulation, it is resulted that the fuel channels fail when the fuel clad temperature reaches about 900℃ and PT temperature reaches about 600℃.

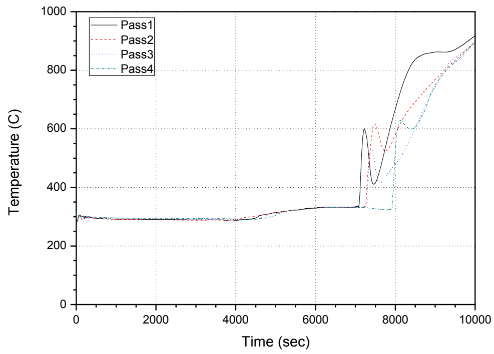

Fig.3. Maximum Temperature of PT (circuit analysis)

The channel failure times are estimated for all core passes and the results are shown in Table Ⅱ. S10 channel in core pass 1 is the first failed channel and the channel failure occurs at about 6100s. S10 channel is the first failed channel and same for the results of the other core passes as well.

The channel failure first occurs at about 700s later compared to fuel clad heat-up start time predicted from circuit analysis.

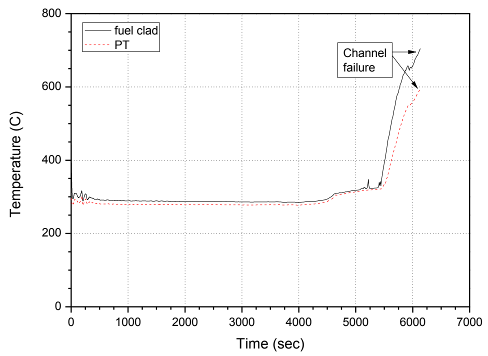

Fig.4. Temperature behavior of fuel clad and PT for S10 channel (single channel analysis)

Table Ⅱ: Channel Failure Time (single channel analysis)

Channel	Channel Failure Time (sec)			
	Pass 1	Pass 2	Pass 3	Pass 4
A09	7826	7979	8618	8555
B10	8106	7564	8627	8595
G05	6315	7938	8580	8556
L03	6528	6783	6953	7299
O06	8220	7023	7251	8841
O6M	6543	6892	6907	7670
S10	6138	6307	6676	6863
W10	8155	8387	8443	8776

4. Conclusion

The channel behavior under the loss of heat sink(LOHS) is estimated in this analysis. The first channel failure occurs at 6100s after initiation of the accident. The fuel clad temperature is predicted to start increasing at 5400s from circuit analysis. If the fuel channel failure time is predicted from the result of circuit analysis without single channel analysis, the prediction of channel failure time assumed from the fuel clad heat-up start time in the circuit simulation is acceptable under the loss of heat sink.

5. Acknowledgements

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