Transactions of the Korean Nuclear Society Fall Meeting
Ilsan, October 24-25, 2019

Effect of Pressure Tube Creep and Feeder Pipe Thinning on the Nominal Channel Flows for CANDU Reactor

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1. Introduction

We have developed a computer code PTLEAK [1] which can evaluate the channel flow and dry-out margin for 380 fuel channels of CANDU reactor. PTLEAK has a capability of calculating channel flows and margin to dry-out in the fuel channel after a break at any location within the flow path from inlet header to outlet header and computing the effect of pressure tube creep and feeder pipe thinning on the steady state channel thermal-hydraulics with or without breaks at any chosen location between headers. Reference 1 described some example analysis results for the code verification. The examples include a comparison of nominal flows from PTLEAK and design data at full power condition and a comparison of pressure drop along the pressure tube against design data for high power channel. Through those analyses, the code was verified its capability.

In this study, we have carried out a series of analysis to see the effect of pressure tube creep and feeder pipe thinning on the nominal channel flows for CANDU fuel channel by using PTLEAK code. Also, we have evaluated an example of the inlet feeder pipe break accident to see the effect of break size on the fuel degradation using PTLEAK. PTLEAK code was developed to have an ability of identifying the range of breaks that causes flow reduction on some or all of the fuel string down-stream of the break. Through those simulations, we could confirm the capability of PTLEAK code and the results will be utilized to check a conservatism of the former safety analysis results.

2. Channel Flow Analysis Considering PT Creep and Feeder Piped Thinning

Major pressure drop for low power channels which have 3.5” feeders occurs at the feeders. For these channels an increase in internal diameter of the feeders by 1-2 mm due to thinning would result in a significant increase in nominal flow through the channels. Effect of high power channel flows of feeder thinning would be lower as they incorporate higher pressure drop in the fuel region. Since for high power channels the majority of pressure drop is in the fuel region, they are more susceptible to flow changes due to pressure tube creep.

In order to consider the effect of pressure tube creep on the nominal channel flow, diametrical creep profile as shown in Fig. 1 was applied in the simulation.

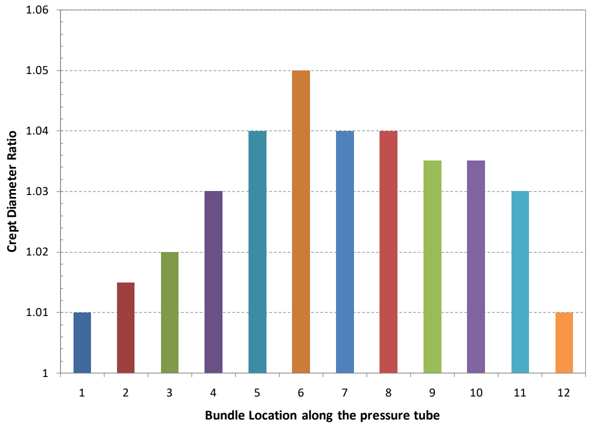

Fig. 1. Diametrical creep profile used in the analysis

2.1 Effect of PT Creep on Nominal Channel Flow

In order to evaluate the effect of pressure tube creep, the flow in a channel was evaluated with increased flow area along the pressure tube using a flow convergence logic for the stated header to header pressure differential. Serial calculations for all channels assuming their respective creep profile for each channel gives the increase in channel flows without a break in the system that range for about 2%-3% for the lowest flow (high flow resistance) outer channels to about 10%-12% for high flow (low resistance channels) as summarized in Fig. 2.

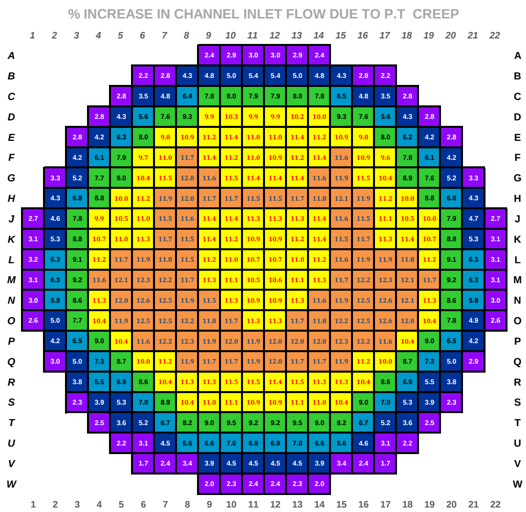

Fig. 2. % increase on channel flows due to PT creep

2.2 Effect of Feeder Thinning on Nominal Channel Flow

Effect of feeder thinning on nominal channel flows (assuming that the header conditions are invariant) was calculated by assuming uniform 1.5 mm and 1 mm wall thinning of the inlet and outlet feeders, respectively. Fig. 3 shows that the changes in nominal channel flows are greatest for low power, small diameter flow channels.

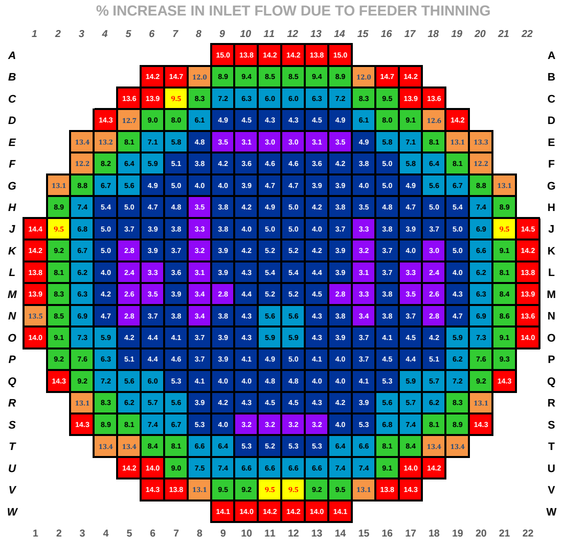

Fig. 3. Increase in channel flows due to feeder thinning

2.3 Effect of Feeder Thinning and PT Creep on Nominal Channel Flow

Fig. 4 shows that the overall change in flows for the same combination of feeder thinning and a pressure tube enlargement is pretty much constant across the reactor core.

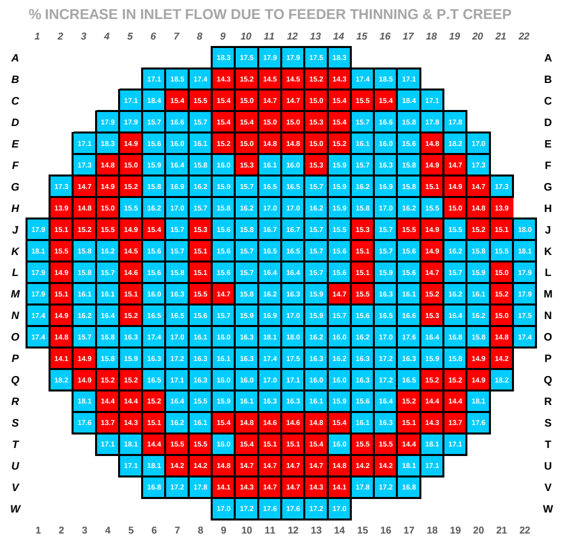

Fig. 4. Increase on channel flows due to feeder thinning as well as pressure tube creep

3. Analysis of Flow Degradation Owing to the Inlet Feeder Break

PTLEAK code was structured to allow investigation of a break at any location by specifying the location of the flow element (inlet feeder, inlet end fitting, pressure tube, outlet end fitting, outlet feeder) and its numerical count from either the beginning or the end of a given region (e.g. 4th from the end of the outlet feeder region; second from the beginning of the PT region, etc).

In a systematic way, the code goes through a whole range of break discharges (break sizes) and tabulates the results for each of the 380 fuel channels, the range of break sizes that causes a dry-out. Minimum break size (or discharge) corresponds to a break that still has a flow in the positive normal direction. Maximum break size (discharge) is the one that causes a reverse flow. Any break location upstream to the end of last fuel bundle can cause a decrease in cooling flow to the fuel downstream of the break location.

As an example analysis, a range of break sizes at the end of inlet feeder at the Gray-lock were postulated. A large amount of output is generated for each of the 380 fuel channels. A summary file contains data on channel flows in response to a range of break discharges. A detailed computation results file contains data on pressure and flow distributions for all break sizes at the chosen location.

Results are summarized in Fig. 5, where for channel A-12 it is shown that a break of discharge greater than 10.4 kg/s and less than 24 kg/s, at least one fuel bundle in that channel will be in dry-out. Note that larger breaks cause reverse flow in the channel of magnitude sufficient to provide adequate heat removal from the fuel bundles.

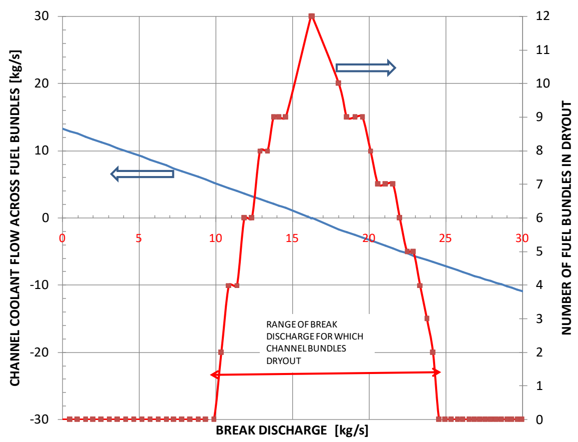

Fig. 5. Range of break discharges that cause a bundle to dry-out down stream of the break

Fig. 6 and Fig. 7 show PTLEAK prediction of the range of break discharge rates (the corresponding break sizes are in Fig. 8 and Fig. 9) that may cause dry-out in the fuel bundles downstream of the break.

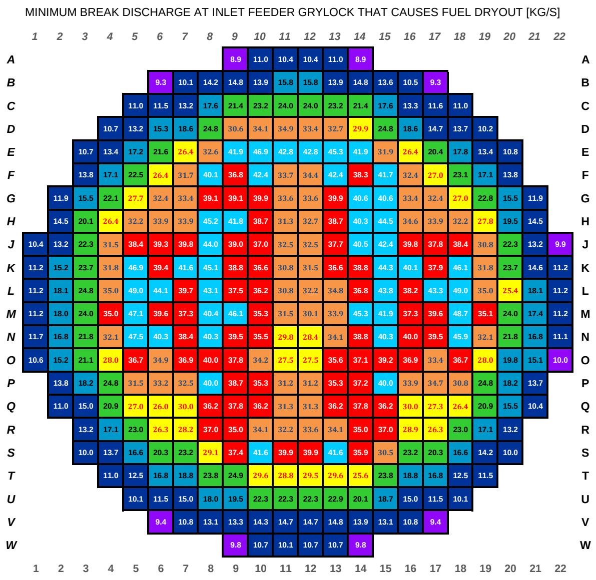

Fig. 6. Minimum break discharge at inlet feeder gray-lock that causes fuel dry-out [kg/s]

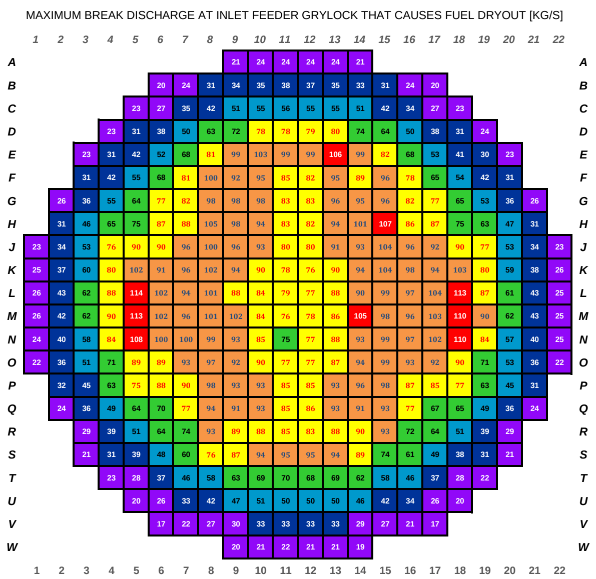

Fig. 7. Maximum break discharge at inlet feeder gray-lock that causes fuel dry-out [kg/s]

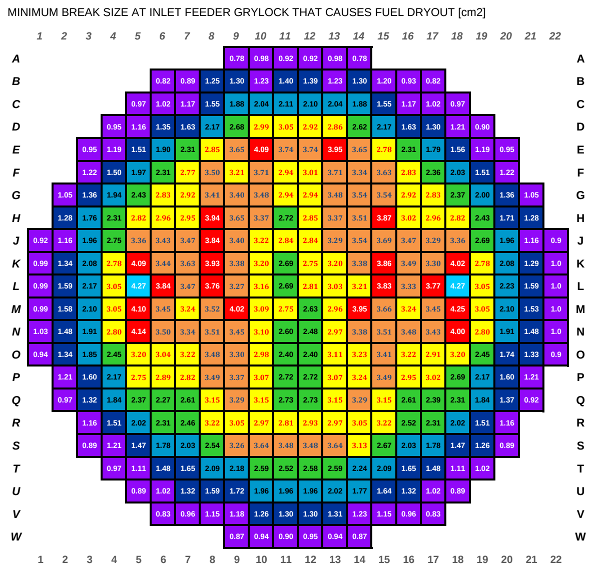

Fig. 8. Minimum break size at inlet feeder gray-lock that causes fuel dry-out [cm^2]

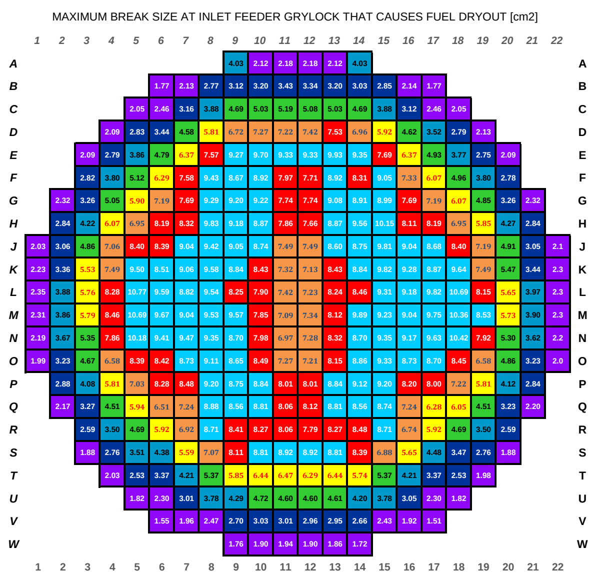

Fig. 9. Maximum break size at inlet feeder gray-lock that causes fuel dry-out [cm^2]

4. Conclusions

We have carried out a series of analysis to see the effect of pressure tube creep and feeder pipe thinning on the nominal channel flows for CANDU fuel channel by using PTLEAK code. Also, we have evaluated an example of the inlet feeder pipe break accident to see the effect of break size on the fuel degradation.

From the analysis results using PTLEAK, we confirmed that the cause of major pressure drop for low power channels occurred at the feeders and fuel bundle region for high power channels. Also we could obtain the range of break discharge rate (break size) which may cause the flow degradation, which means the stagnation flow when the feeder pipe breaks.

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science and ICT). (NRF-2017M2A8A4017282).

REFERENCES

[1] J.Y. Jung, E.H. RYU and S. Nijhawan, “PTLEAK – Program for Assessing the Channel Flow and Margin to Dryout of the CANDU Fuel Channel”, Transactions of the KNS Spring Meeting, Jeju, Korea, May 23-24, (2019).