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Evaluation of Reactor Channel Response to a Sudden Pressure Tube Crack in a CANDU Reactor

Jong Yeob Jung [a*], YongMan Song [a], Sunil Nijhawan [b]
[a]*Thermal Hydraulics Severe Accident Research Division, KAERI, Daedeok-daero 989-111, Daejeon, Korea*
[b]*Prolet Inc., Toronto, Canada*
[*]*Corresponding author: agahee@kaeri.re.kr*

1. Introduction

A loss of CANDU pressure tube geometric integrity due to a hole or a long crack can result in degradation of fuel cooling if the Calandria tube survives the pressurization caused by sudden fluid discharge into the otherwise unpressurized annular space been the Pressure and Calandria tube. The magnitude of loss of fluid into the feeder cabinet through potential ruptures of the end fitting bellows strongly affects the thermal behaviour of fuel bundles under the crack as well as those downstream of the crack. It may be insufficient to trigger a reactor trip and the fuel heatup will be fast (~100°C/sec) and immediate in those regions of the channel that experience a degradation in cooling caused by coolant largely bypassing internal regions of some fuel bundles. If the fuel heatup is severe it may lead to early release of fission products into the containment as well as energetic and explosive destruction of the channel. Therefore, a systematic study of fuel channel responses to pressure tube cracks is warranted, especially because pressure tube integrity is a grave concern in CANDU reactors that have significantly aged. Fig. 1 shows the schematic diagram of a fuel channel in CANDU reactor.

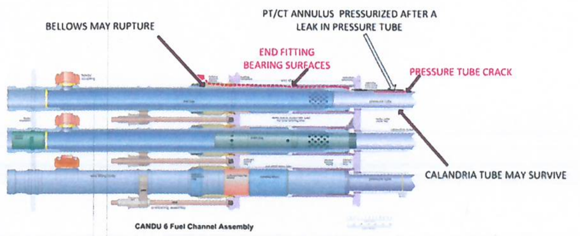

Fig. 1. Schematic diagram of fuel channel of CANDU reactor.

2. Background

A pressure tube rupture with Calandria tube intact occurred in Pickering CANDU (Unit 2, channel G16, Aug 1983) but there was no fuel heatup reported as the 2m crack occurred from the channel centre to downstream end of the channel. In another PT failure case (Channel K6 at Bruce) the Calandria tube was also ruptured. Such an accident can cause extensive in-core damage to adjacent channels and have other consequences.

3. Assessments

A new KAERI computer code PTCRACK assesses the on power thermal-hydraulic response of fuel bundles in a fuel channel following onset of a crack or a rupture in its Pressure Tube with Calandria tube surviving the event. It captures the effect of differences in power and feeder geometries by assessing the response of all 380 fuel channels sequentially by assuming that each channel has the same crack. Such a crack can result in fluid discharges into the feeder cabinet of magnitude that may not be detected early and the reactor will remain operational until another event like a channel failure due to hot fuel interactions or degradation in D_2O inventory occurs.

Following a longitudinal rupture the decrease in heat removal from certain segments of the fuel channel is caused not only by the coolant bypassing the inner sub-channels of the bundle cores but also by the less resistive flow path made available in the PT/CT annulus and the partial or complete loss of coolant through the channel bellows as shown in Fig. 2

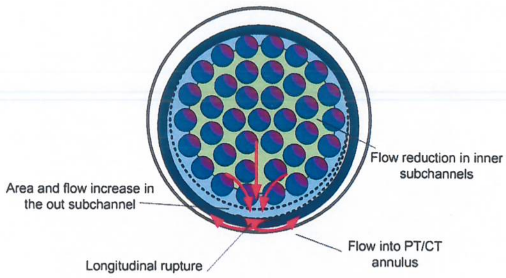

Fig. 2. Flow change after the pressure tube rupture.

Separate analyses using the computer code PTLEAK have demonstrated that all 380 CANDU 6 fuel channels respond differently to the same size break in the flow path between headers. In general, a rupture will cause fuel cooling to degrade and parts of the fuel bundles to abnormally heatup as shown in Fig. 3.

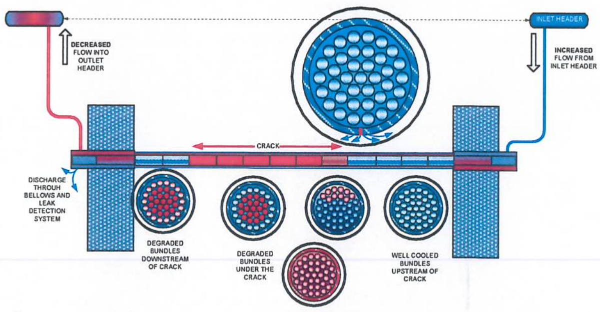

Fig. 3. Fuel heatup along the channel axial direction.

CANDU fuel channels by themselves are geometrically all alike but their response to a sudden loss of coolant due to a leak or a break in a feeder or the pressure tube depends upon a number of factors that include crack geometry, incipient pressure tube creep, bellow integrity and any fluid loss through bellows, channel power and power profiles as well as feeder geometry. Therefore analyses are carried out for all reactors channels. Recall that CANDU channels are flow power matched (except at Bruce) such that the ratio of power to nominal flow is around varies between 225 and 275 [Kw/(kg/s)]. This is achieved by having low power channels sport more resistive feeders. This has a profound effect on channel response to any geometric changes in the flow path between headers including pressure tube creep as well as braeks and ruptures in the pressure tube.

It is estimated that the largest fluid loss through two bellows may be of the same order of magnitude as the nominal flow through a low power channel (~10 kg/s); therefore in fuel channels with high nominal flows and a larger margin to dryout, a degradation in cooling due to a pressure tube crack will have a different significance than a lower power channel with lower overall fluid exchange rates.

The paper presents summary results for a range of pressure tube cracks for all Wolsong channels and demonstrates how low power channels may be more vulnerable to severe consequences following certain cracks that do not cause sufficient degradation of cooling in higher power channels.

Fig. 4 summarizes the peak sheath temperatures in all reactor channels after a 4m crack starting at 1m and 2mm in width. It was assumed that the two end fitting bellows rupture and cause 5 kg/s of water loss through each. It is shown that of all fuel channels that only low power channels experience fuel dryout (length of dryout fuel bundles shown; channels with no dryout are in white).

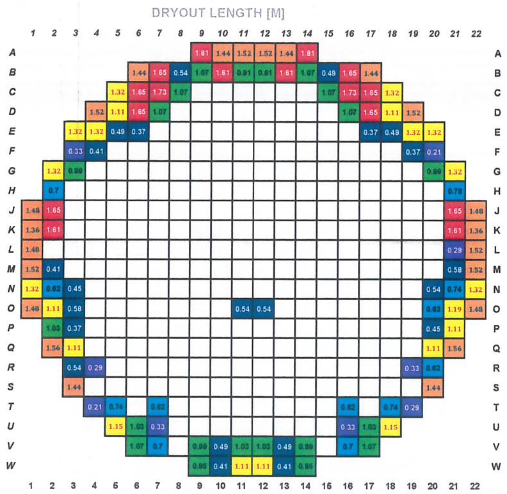

Fig. 4. Schematic map of peak sheath temperature.

Fig. 5 shows the sheath temperature results in the case of same loss of 10 kg/s for the same crack geometry but from only the inlet bellow the distribution of core heatup more extensive.

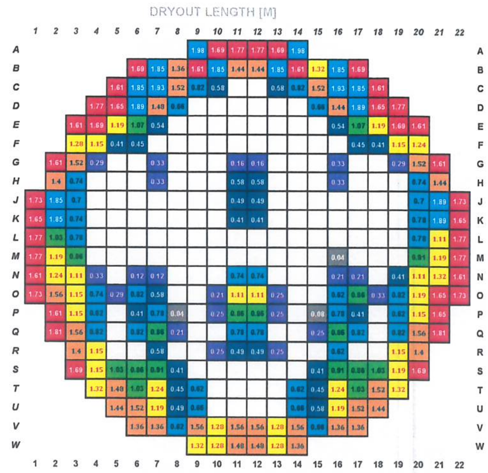

Fig. 5. Peak sheath temperature when the loss of 10 kg/s.

4. Conclusions

The computer code PTCRACK used for analysis computes two-phase D_2O flows in over 500 radial and axial flow paths in the crack region and also models the end fittings and channel specific feeders as shown in Fig. 6.

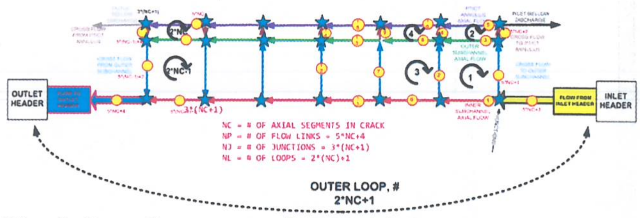

Fig. 6. Overall structure of PTCRACK computer code.

All 4 fuel rings of CANDU fuel bundle are modelled with an average fuel pin in each ring modelled with upto 200 radial nodes. The new computer code allows steady state investigation of thermal consequences of such accidents with calculations to establish if the floew degradation causes fuel dryout and use of methodologies to evaluate post CHF fuel behaviour; helps identify detection and mitigation measures and helps improve the safety assessments for Wolsong licensing submissions.

Acknowledgments

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References

[1] AECL 8850- The examination of the ruptured Zircaloy-2 pressure tube from Pickering NGS unit 2.