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CANDU 6 Large Break LOCA Analysis with a Realistic Break Opening Model

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1. Introduction

When analyzing LBLOCA(Large Break Loss-Of-Coolant-Accident), traditionally a conservative break opening model for a guillotine break has been used. It is assumed to develop instantaneously from an intact pipe to a double-ended guillotine break for an extremely short time, such as a time period less than 0.01 second. Meanwhile, a new break opening model was proposed by the reference [1]. It could be used alternatively as a guillotine break model in LBLOCA Analysis for a CANDU 6 type Point Lepreau NPP(Nuclear Power Plant). The new break opening model assumes a gradually developing break for 5 seconds, which was decided based on various experimental pipe fracture database. The new model is more realistic than the existing and conservative model. So, in analyzing LBLOCA, safety margin is expected to increase and consequences of the accident is expected to be mitigated.

A preliminary analysis on LBLOCA with the new break-opening model applied was performed[2] for a CANDU 6 type, Wolsong NPP only with a thermal-hydraulic code, CATHENA(Canadian Algorithm for THErmal-hydraulic Network Analysis)[3] in order to know effects of applying the new model. In the paper, the thermal-hydraulic(TH) analysis results showed that maximum temperatures of fuel sheath and fuel centerline were decreased a little bit using a power pulse data which had been produced with the existing break-opening model. In the present paper, in order to assess quantitative and accurate safety margins in LBLOCA analysis with the new break-opening model applied, LBLOCA Analysis were performed including power pulse, TH and fuel analysis and their results were presented.

2. Analysis Scope and Method

Only 100% break case at ROH(Reactor Outlet Header) was analyzed in order to reflect the new break opening model as it is. The 100% break size is the severest case at ROH.

Coupling calculation between the RFSP(Reactor Fueling Simulation Program)[4] physics code and the CATHENA TH code was performed in order to investigate the effect of the new break opening model on the power pulse. With the new power pulse data from the coupling calculation, TH calculations were done with CATHENA code for checking temperatures of fuel sheath and fuel centerline. Then fuel analysis with the ELOCA(Element Loss Of Coolant Accident)[5] code was carried out to find out how many fuel elements were broken.

In the TH analysis, a CATHENA system model and 6 representative single channel models for a Wolsong NPP were used. The CATHENA system model represents for PHTS(Primary Heat Transport System) and secondary side systems and is used for predicting the whole system TH behavior. The 6 single channel models are representative channels for 95 fuel channels of 1/4 reactor core and are used for checking fuel sheath and pressure tube temperatures and for providing TH boundary conditions for subsequent fuel analysis. Among the 6 representative channel, there is a channel named ‘O6mod’, which was modified from normal O6 channel into a high power channel to have the channel power limit(7.3 MW) and the bundle power limit(935 kW) at 2 middle bundles. So it is used for checking the highest fuel and sheath temperatures.

Totally 2 cases were simulated: one with the new break opening model and the other with the existing break opening model. Then their results were compared each other to see quantitative differences in power pulse data, fuel sheath temperatures, fuel centerline temperatures, and the number of broken fuel element.

3. Results

Fig. 1 compares results of power pulse calculations with the new break opening model and with the existing model. The normalized power transient with the new model has a lower peak than the data with existing model, and the peak value was appeared to be shifted more than about 1 second. The normalized powers were 1.41 at 2.50 seconds in the case with the new model and 1.48 at 1.35 seconds in the case with the existing model. In short, the power pulse was moderated to some extent due to slowly increased void fraction in the reactor core by a gradually developing guillotine break. Meanwhile, the reactor was tripped to shutdown at 2.5 seconds in the case with the new break opening model while the break is still being developed.

Fig. 2 shows difference in discharged mass flow rates from the breaks. Especially within 10 seconds after the breaks start to occur, the difference was noticeable. These were directly affected by the difference in the break opening models. With the new break opening model, coolant was discharged more slowly in first five seconds. So, void fraction was increased slowly and then the power pulse due to void reactivity was calculated to be lower than the case with the existing model.

Fig. 3 describes maximum temperatures of fuel sheath and fuel centerline in the high power single channel, O6mod. It shows generally similar trends in transient temperature, but peak temperatures of sheath and fuel centerline were lower in the case with the new break opening model. Maximum fuel sheath temperatures were 850.0℃ at 11.02 seconds in the case with the new model and 951.8℃ at 2.46 seconds in the case with the existing model. Maximum fuel sheath temperature was decreased by about 100℃ with the new break opening model.

There was no fuel element failure in the case with the new break opening model while there were 72 failed fuel elements in 2 bundles of the high power channel, O6mod in the case with the existing model as in Table 1.

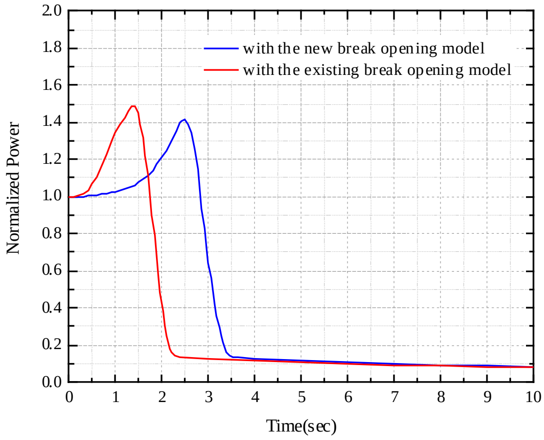

Figure 1. Whole core power pulse data(normalized power)

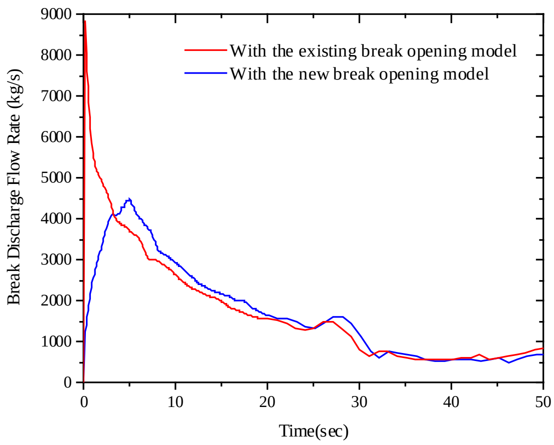

Figure 2. Discharged mass flow rate from the break

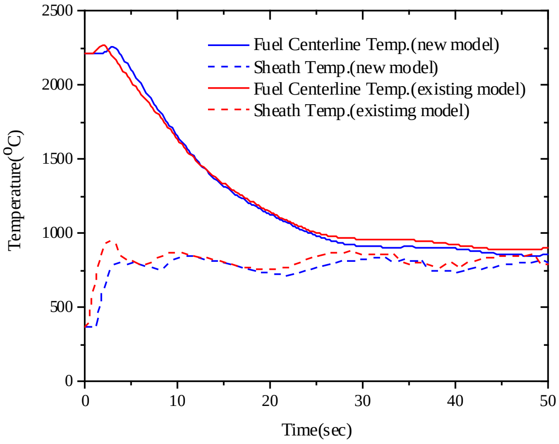

Figure 3. Maximum fuel centerline and sheath temperatures of the high power channel, O6mod

Table 1. Extent of fuel failure in the case with the existing model

Channel (Channel Power)	Earliest Failure Occurs at (sec)	Number of Bundles with Fuel Failure	Number of Failed Elements
O6mod (7.3 MW)	45.8	2	72
O6(7.0 MW)	-	0	0
S10(6.6 MW)	-	0	0
G5(6.0 MW)	-	0	0
B10(5.0 MW)	-	0	0
W10(4.0 MW)	-	0	0

The lower and shifted power pulse and slowly discharged coolant condition make the fuel centerline and sheath temperature lower in first 5 seconds. This lower fuel temperature condition might be the cause that fuel elements were not failed in the case with the new break opening model.

4. Conclusions

From the results above, it was confirmed that consequences of the LBLOCA case with the new break opening model was mitigated and that safety margin of the case with the new model would be increased to some degree.

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