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A Validation of the CATHENA Fuel Channel Model for a Post Blowdown Analysis against a High Temperature Thermal-Chemical Experiment for a Ballooned CANDU Fuel Channel

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1. Introduction

To form a licensing bases for the new methodology of a fuel channel safety analysis code system for CANDU-6, a CATHENA model of the post-blowdown fuel channel analysis for an aged fuel channel with a crept pressure tube has been developed, and tested for a high temperature thermal-chemical experiment CS28-2. Pursuant to the objective of this study the current study has focused on understanding the involved phenomena such as the radiation and convection heat transfer and high temperature metal-water reaction of the 28-element cluster type fuel bundle in the crept pressure tube, their interrelations, and how the treatment of the psudo-subchannels in the 1-D thermalhydraulic code can affect the prediction with an attempt to properly account for the important physics of the involved phenomena, and how it relates to the experimental results. The transient simulation results for the Fuel Element Simulators (FES) of three fuel rings and the pressure tube were quite encouraging provided some adjustment of the fuel channel annulus gas thermal conductance is used. However this raises a question on how the authors can justify using the adjusted thermal conductance for the CO_2 gas gap. Various possible arguments for justifying the obtained results based on an adjusted gap thermal resistance were proposed and discussed. In spite of these difficulties, through this study, it was found that the radiation heat transfer model of CATHENA among FES of three rings and the pressure tube as well as the exothermic metal-water reaction model based on the Urbanic-Heidrick correlation are quite accurate and sound even for the offset cluster fuel bundle of an aged fuel channel

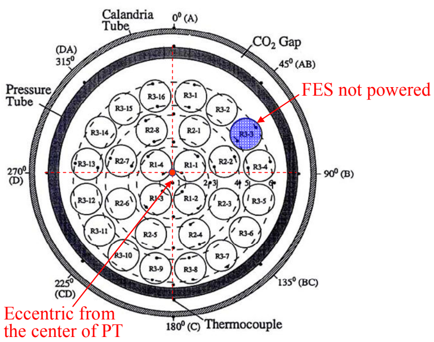

Fig.1 Cross Section of the CS28-2 Test Bundle and Failed Heater Location

2. Radiation Heat Transfer Model

In CATHENA, the radiation model calculates the heat exchange due to a thermal radiation among the solid component models; between the FES facing each other, between the FES and the pressure tube, and also between the pressure tube and the calandria tube. The view factor matrix is generated separately by using the utility program MATRIX. An emissivity of 0.8mm (based on ZrO_2) is used for the fuel sheaths and the inside/outside surfaces of the pressure tube and 0.34 for the inside surface of the calandria tube.

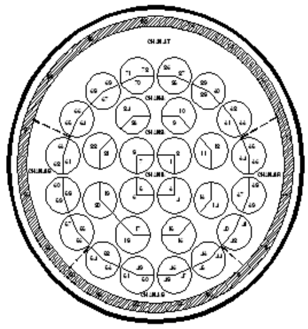

Fig.2 CATHENA Solid Structure Model and Subchannel Model for CS28-2 Experiment

3. CATHENA Simulation Results and Discussion

One difficulty was that even after accounting for all the available models of the CATHENA code for the heat transfer between the pressure tube and the calandria tube, there still remains a significant discrepancy between the measured pressure tube temperatures and those predicted by CATHENA. Thus for a proper adjustment of the CATHENA simulation, a multiplying correction factor for the CO_2 conductivity is necessary to match the measured pressure tube temperature applied, though the actual reason for an enhanced heat transfer rate is not yet estblished. And as result, a good agreement of the fuel element simulators (FES) and pressure tube were obtained as shorn in Fig. 3 for the steady state. and the following results for the transient shown in Figs 4 to 5..

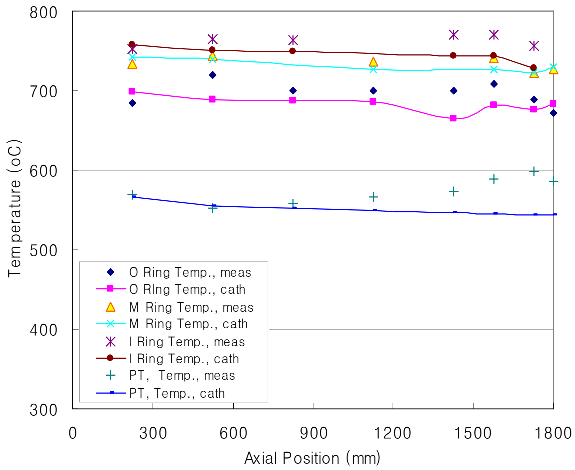

Fig.3 Measured vs. Predicted Inner, Middle and Outer Ring FES and the PT temperatures along the axial direction for the Initial Steady State of CS28-2 Experiment]

The transient simulation result was quite good for the FES of three fuel rings and the pressure tube what were quite good as shown in Figs. 5 to 8. This leaves a question as to how the transient FES and pressure tube temperature can be predicted so well in spite of an insufficient justification for using the "non-participating medium assumption" for the CO_2 gas gap.

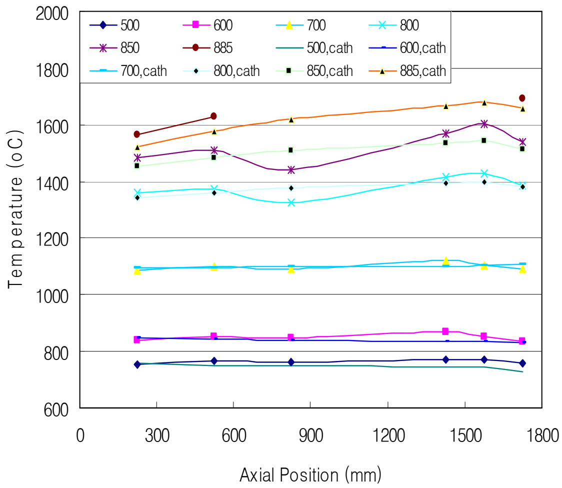

Fig. 4 Inner Ring FES temperature along the axial direction compared with the measured one

4. Conclusion

From all the above mentioned facts and discussions, the authors have drawn the following conclusions: With the adjusted CO_2 gap thermal resistance, the current fuel channel model of CATHENA is shown to predict all the

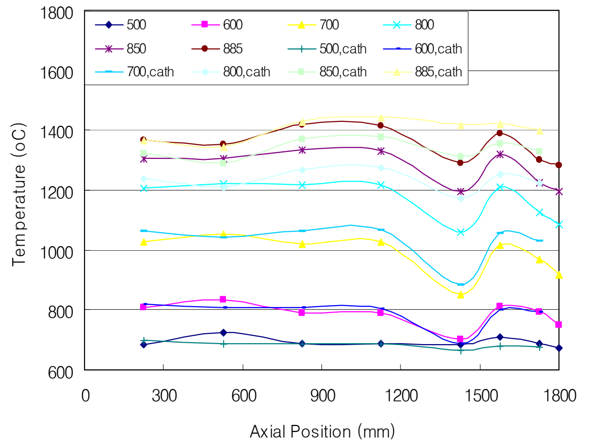

Fig. 5 Outer Ring FES temperature along the axial direction compared with the measured one during the heating stage 3.

temperatures of the inner ring, middle ring, outer ring as well as the pressure tube satisfactorily, considering that the uncertainty of the temperature measurement is ±1.2%, which corresponds to ±22.5°C for a temperature of 1800°C, that of the electric power ±4.4%, and the uncertainties for the other boundary condition parameters. The pressure tube temperature can be matched to the measured ones by applying a correction multiplier to the CO_2 conductivity as there is no other way in CATHENA code to account for the enhanced heat transfer between the PT and CT by using the currently available radiation heat transfer model. It was confirmed that neither a radiation nor the axial convective CO_2 cooling with a radiation absorption accounted for, enhanced by the buoyancy driven secondary natural convective heat transfer in the gap confined by both a hot and a cold wall can explain this enhanced heat transfer observed in this experiment. Through this study, several possible reasons or factors could be identified that may significantly affect an accurate prediction of the initial steady state and following transient temperatures of the experiment.

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