A CATHENA Fuel Channel Model for CANDU-6 LBLOCA Post Blowdown Analysis for a High Temperature Thermal-Chemical Experiment CS28-1

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1. Introduction

During the post-blowdown phase of a postulated Loss of Coolant Accident (LOCA) with impaired Emergency Core Cooling (ECC) in CANDU reactors, either saturated or superheated steam is considered to be the only coolant available in the fuel channel. In this condition the dominant path of removing the decay heat is considered to be the discharge via radiation heat transfer from the fuel elements to the huge moderator across the pressure tube and calandria tube[1]. As too high temperature of the fuel may initiate the auto-catalytic exothermic zircaloy-steam metal water reaction and, if progressed to worse situation, the breakdown of the mechanical integrity of the fuel sheath may cause collapse of the fuel bundle in the fuel channel, the confirmation of the adequate cooling capability of this heat transfer mechanism has been of great concern to the CANDU-6 safety analysis[2]. Recently KAERI has developed a new CANDU fuel channel safety analysis code system where the CHAN-II code is to be replaced by CATHENA for the post-blowdown phase analysis of the CANDU-6 fuel channel under LBLOCA w/o ECC[3]. For this new CATHENA model the validation studies have been under way, and one of them is the validation against a high-temperature thermal-chemical experiment called CS28-1[4]. As quite a comprehensive experimental data available, this test was intensively studied and simulated using CATHENA code as well as 3D CFD code, CFX, equipped with various radiation models of popularity.

As the major concerns of the post-blowdown fuel channel analysis are how much portion of the decay heat can be discharged to the moderator via radiation and convective heat transfer modes at the expected accident conditions, and thus how high the fuel and pressure tube temperatures can be maintained, and how much zirconium sheath would be oxidized to generate H_2 gas, the objective of this study and CATHENA modeling has been focused on understanding these phenomena, their interrelations, and how to maintain good accuracy in the temperature and H_2 generation rate prediction without losing the important physics of the involved phenomena.

The detail description of the CS28-1 experiment is well described in other literature[4] and thus will be omitted here.

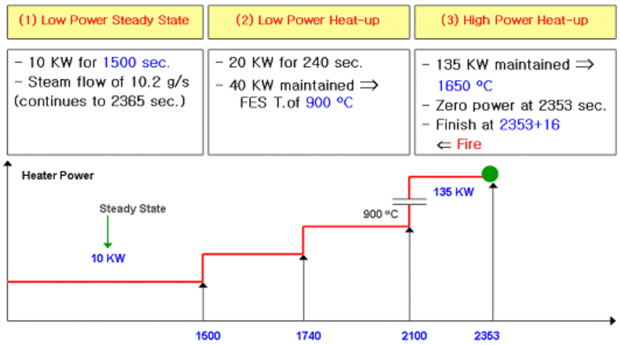

Fig. 1. Test Fuel Bundle Heating Condition during CS28-1 Transient Test.

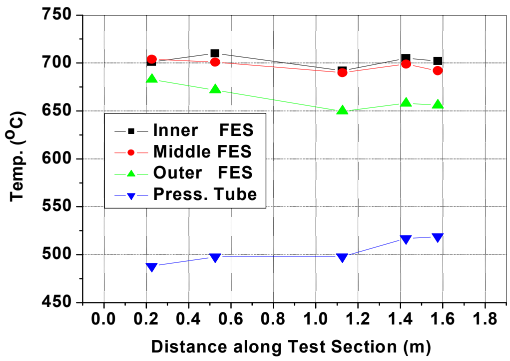

Fig.2. Measured Inner, Middle and Outer Ring FES and the PT temperatures along the axial direction for the Initial Steady State

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 0.8 (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. A view factor matrix between the pressure tube and each of the 28 FES in the detail segmented geometry is generated first, and then converted to the contracted view factor matrix file which is consistent with the solid component models as shown in Fig.3.

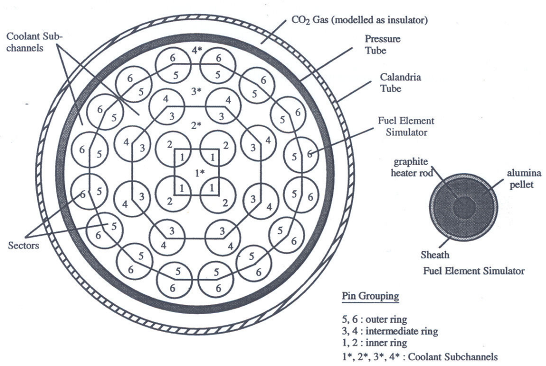

Fig. 3. CATHENA Solid Structure Model and Subchannel Model for CS28-1 Experiment

3. CATHENA Simulation Results and Discussion

One difficulty was that even after accounting all the available model of 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 that predicted. Thus for a proper adjustment of CATHENA simulation, a multiplying correction factor to the CO_2 conductivity necessary to match the measured pressure tube temperature was applied, though the actual reason for enhanced heat transfer rate is not yet found. And as result, a good agreement of the fuel element simulators (FES) and pressure tube were obtained as in Fig. 4 for the steady state.

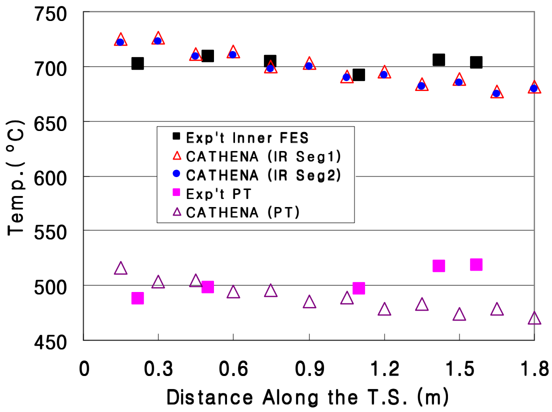

Fig. 4. Inner Ring FES and Pressure Tube Temperatures Compared after CO_2 Conductivity adjustment for Initial Steady State[4]

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

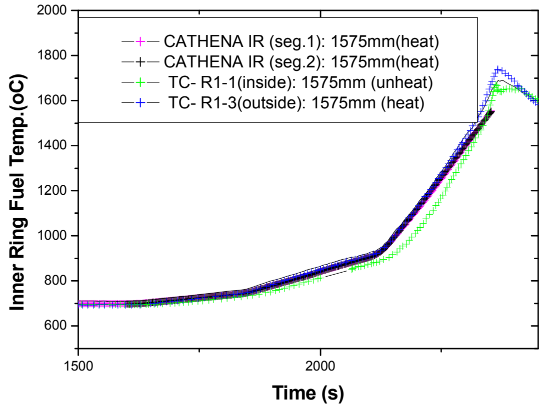

Fig.5. Inner Ring FES Temperatures of the CATHENA Predicted and Experimentally Measured Compared

4. Conclusion

In the case of CATHENA simulation, once the pressure tube temperature is adjusted to be predicted correctly by the CATHENA model, all the remaining temperatures of the inner ring, middle ring and outer ring can also be predicted quite satisfactorily, say to within an accuracy range of $\pm 20^{o}C$, which proves the robustness of the CATHENA radiation model between FES and pressure tube. Another aspect of CATHENA radiation modeling that needs to be justified is that the assumption of transparency in the CO_2 gap between the pressure tube and the calandria tube. If the heat deposition in this gap is not negligible in the pressure tube temperature calculation during the accident, one may examine the current modeling of CATHENA radiation heat transfer. Further in-depth study on the radiation and convective heat transfer phenomena in the narrow CO_2 gas gap is necessary to resolve the existing problem.

REFERENCES

[1] "Wolsong Nuclear Power Plant Units No.2/3/4 Final Safety Analysis Reports", Korea Electric Power Corporation, March 1995.

[2] Q.M. Lei and T.M. Goodman, "Validation of Radiation Heat Transfer in CATHENA," Proceedings of 5th International Conference on Simulation Methods in Nuclear Engineering, Montreal, PQ, Sept. 1996.

[3] Bo W. Rhee, H.T. Kim, B-J Min, J.H. Park, "Development of CATHENA Fuel Channel Model for Integrated Blowdown and Post-Blowdown Analysis for 37-Element CANDU Fuel Channel ", CNS Annual Conference, Toronto, Canada, June 11-14, 2006

[4] Bo W. Rhee, J.H. Park, "Validation of CATHENA Fuel Channel Model for Post Blowdown Analysis against CS28-1 Experiment, II – Transient", CNS Annual Conference, Toronto, Canada, June 11-14, 2006