VALIDATION OF CATHENA FUEL CHANNEL MODEL FOR POST BLOWDOWN ANALYSIS AGAINST CS28-1 EXPERIMENT, II - TRANSIENT

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Abstract

To form a licensing bases for the new methodology of fuel channel safety analysis code system for CANDU-6, a CATHENA model for the post-blowdown fuel channel analysis has been developed, and tested for a high temperature thermal-chemical experiment CS28-1[1].

Pursuant to the objective of this study the current study has focused on understanding the involved 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 transient simulation results for the FESs of three fuel rings and the pressure tube were quite good as proven in the Figs. 3~6. However this raises 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. Through this study, it was found that the radiation heat transfer model of CATHENA among FES of three rings and the pressure tube aa well as the exothermic metal-water reaction model based on the Urbanic-Heidrick correlation are quite accurate and sound. Also it was found that an accurate prediction of the initial condition of the experiment is very important for the accurate prediction of the whole transient as it serves as the starting point of the transient.

1. Introduction

A new methodology of fuel channel safety analysis code system for CANDU-6 has been developed and tested against the relevant experiment CS28-1 for licensing validation. As the major change in this new methodology from the previous one for Wolsong 2,3,4 is the replacement of CHAN-II code with CATHENA code for the post-blowdown fuel channel analysis during LBLOCA w/o ECCS, only the experiment that involves the major phenomena of the post-blowdown is considered. The major safety concern of this post-blowdown phase are the radiation heat transfer among the heat structures such as the fuel, the pressure tube and the calandria tube, the self-catalytic exothermic zirconium-steam reaction rate at the elevated fuel temperatures above about 800°C and the resultant hydrogen generation, the CS28-1 experiment is found to be most suitable for validation of the code and related models.

As the fuel element simulator (FES) temperatures of CS28-1 experiment went up to as high as 1700°C, it is evident the selection of which correlation for the zirconium-steam reaction rate becomes very important to an accurate prediction of fuel temperature and hydrogen amount. In this paper initially the radiation heat transfer model of CATHENA is reviewed and applicability of the model to this experiment is discussed. (optical depth) Then the transient simulation of the fuel bundle heat up not only due to heater power increase but also the onset of self-catalytic exothermic metal-water reaction has been performed.

2. Radiation Heat Transfer Model

Basically the radiation heat transfer model of the CATHENA model of this paper as shown in Fig. 1 is based on the previous work by Lim and et.al.[17] but a significant modification made to the FES model and the associated view factor matrix so as that all the symmetric conditions be met. Also the steady state radiation modeling was revised to match the experimentally measured temperatures of the FES of three fuel rings and pressure tube. The detailed modeling features of the current model can be found in another companion paper in this conference.[15]

The radiation model of CATHENA code calculates the heat exchange due to the thermal `radiation among the solid components based on the non-participating medium assumption. ㅠ Based on the segmentation of the solid structures such as the fuel element, the pressure tube, and the calandria tube, the view factor matrix is generated separately using the CATHENA utility program MATRIX. An emissivity of 0.80 (based on ZrO_2) is used for the fuel sheaths and the inside and outside surfaces of the pressure tube and 0.34 the inside surface of the calandria tube. Using these emissivity values throughout the whole transient can be a source of error as the emissivity of 0.80 is good for the fully oxidized ZrO_2 surface while that of 0.34 is good for the clean Zr metal surface. Furthermore the non-participating medium assumption may be justifiable only for the steam filled fuel channel as the absorption coefficient is 0.08~0.05/(cm-bar) and the optical depth is about 0.125~0.200m where the radius of the fuel bundle is ~0.055m and the smallest clearance between the outer fuel element and the pressure tube is even much smaller than this. However as for the CO_2 gas annulus because of the high absorption coefficient of 0.35/(cm-bar) and thus quite short optical thickness of 0.0286 m whereas the CO_2 gas gap is in the order of about 0.01m, thus the chance for absorption cannot be neglectd. As there seems not any good way of handling natural convective cooling of the both internally and externally heated CO_2 gas flow in the PT/CT annulus[14] in the current CATHENA code modeling, predicting the pressure tube temperature reasonably against CS28-1 experiment was not possible for the initial steady state condition. Nevertheless by employing a corrective multiplying factor to the CO_2 gas conductivity, the current CATHENA model could predict the pressure tube temperatures as well as those of the FESs' in the inner, middle and outer fuel rings quite well[15].

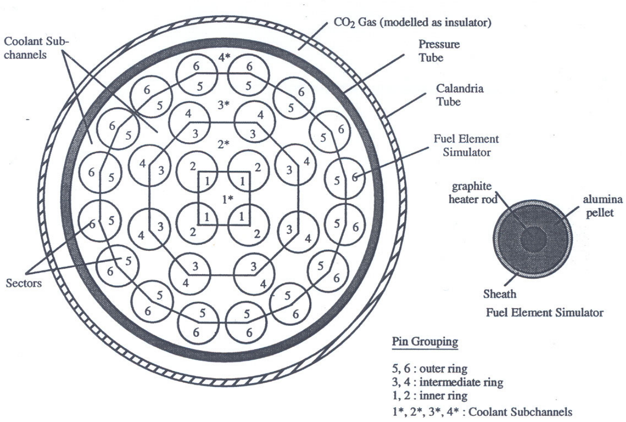

Fig. 1. Solid Structure Model and Subchannel Model for CS28-1 Experiment[15]

3. Transient Simulation of CS28-1 Experiment

As the detailed description about the experiment CS28-1 is given in the reference 2, the explanation of the experiment is left out here, and only a summary of the experiment power condition is given in Fig.2. As for the model for the metal-water reactions and hydrogen/heat generation, the Urbanic and Heidrick correlation[16] is used for the zirconium/steam reaction rate calculation on the fuel sheath and inner surface of the PT. This zirconium/steam reaction adds more heat generation both on the sheath outside surface and the inside surface of the PT on top of the channel decay power. The thickness of the oxide layer, volume of hydrogen produced, and the heat generation for the metal water reaction is calculated. The effect of the generated hydrogen in reducing the amount of steam available for the reaction is modeled. This "steam starvation" calculation does not feed back to the channel thermohydraulic calculation.

Using the test conditions as the boundary condition of CATHENA simulation and the adjusted initial steady state conditions[15], a transient analysis has been carried out. The transient simulation results for the FES with three fuel rings and the pressure tube were quite good as shown in Figs.3 to 6. This raises a question whether the "non-participating medium assumption" for the CO_2 gas gap is really good or not and can be justified for this CO_2 gap case.

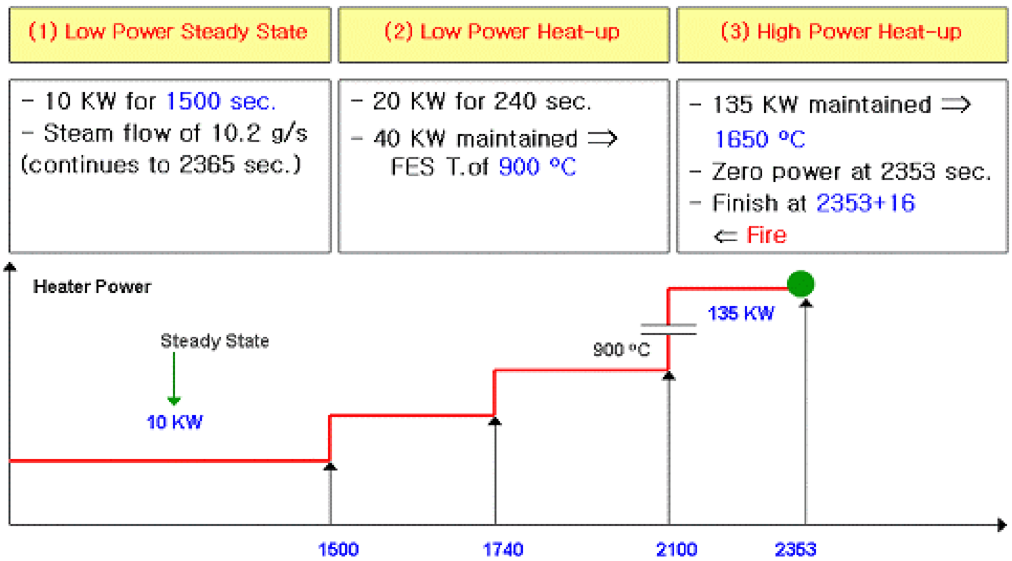

Fig.2. Test Fuel Bundle Heating Condition during CS28-1 Transient Test.

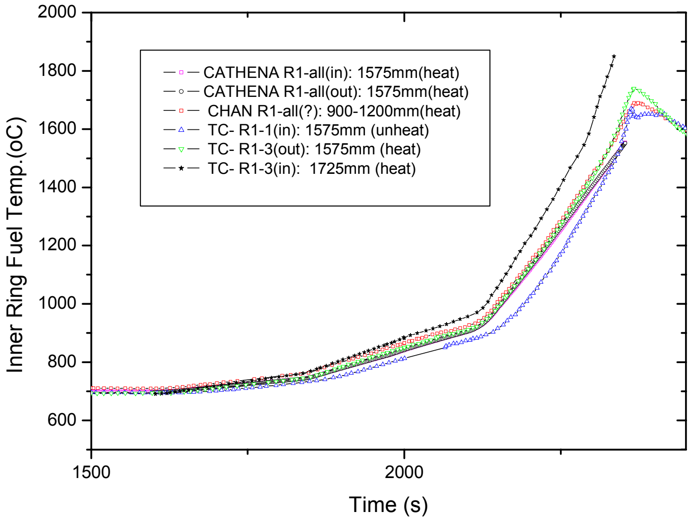

Fig.3. Inner Ring FES Temp. Comparison

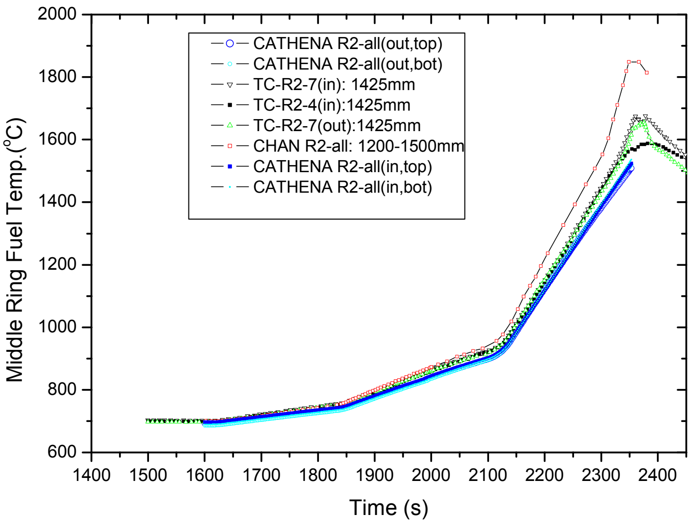

Fig 4. Middle Ring FES Temp. Comparison

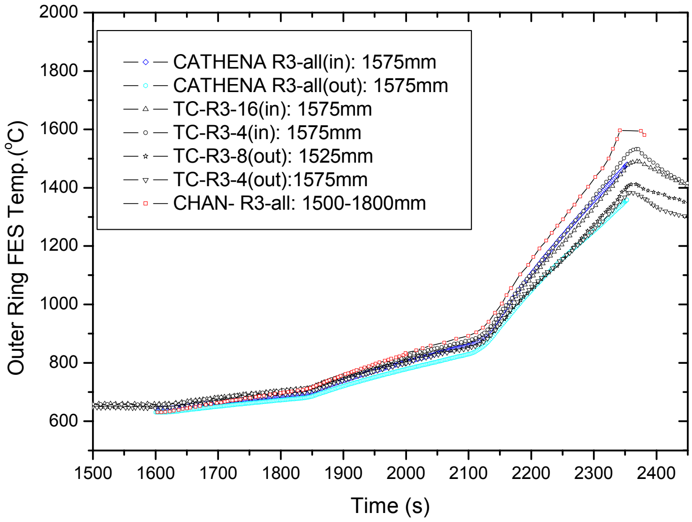

Fig.5. Outer Ring FES Temp. Comparison

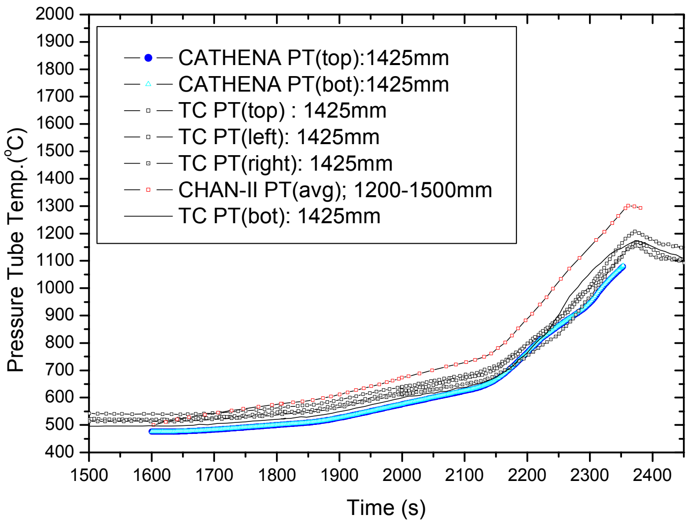

Fig. 6. Pressure Tube Temp. Comparison

4. Discussion and Conclusion

A CATHENA model for the post-blowdown fuel channel analysis has been developed, and tested for a high temperature thermal-chemical experiment CS28-1. The transient simulation results for the FESs of three fuel rings and the pressure tube were quite good as proven in the Figs. 3~6. However this raises 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. Through this study, it was found that the radiation heat transfer model of CATHENA among FES of three rings and the pressure tube aa well as the exothermic metal-water reaction model based on the Urbanic-Heidrick correlation are quite accurate and sound. Also along with the companion paper[15], it was found that an accurate prediction of the initial condition of the experiment is very important for the accurate prediction of the whole transient as it serves as the starting point of the transient.

Another aspect of CATHENA radiation modeling that needs to be justified is that the assumption of non-participating medium for the CO_2 gas 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 and modify to include the absorption and re-emission of the thermal radiation in this gap.

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