Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Transient Moderator Simulation Using CFX10-CAMO, a CANDU Moderator Analysis Model Based on a Coupled Solver

Churl Yoon and Joo Hwan Park
Korea Atomic Energy Research Institute, 150 Dukjin-Dong, Yusong-Gu, Daejeon 305-353, Korea
Phone: +82-42-868-2128, Fax: +82-42-868-8256, E-mail: cyoon@kaeri.re.kr

1. Introduction

When a PHT(Primary Heat Transfer) system fails to remove excess heat from fuel channels for some loss of coolant accidents(LOCA's) in CANDU NPP's, the fuel channel temperature could increase until the pressure tube strains (i.e., balloon or sag) to contact its surrounding Calandria tube.(PT/CT contact) Following a PT/CT contact, there is a spike in the heat flux to the moderator surrounding the Calandria tube, which may lead to a sustained CT dryout and also a failure of a fuel channel. The prevention of a CT dryout following a PT/CT contact depends on the local moderator subcooling. That is, fuel channel integrity depends on the capability of the moderator to act as the ultimate heat sink for some LOCA's in a CANDU reactor.

In KAERI, Yoon et al.[1] developed a CFD model for predicting a CANDU-6 moderator temperature on the basis of a commercial CFD code CFX-4(ANSYS Inc.). This analytic model has the strength of modelling the hydraulic resistances in the core region and accounting for a heat source term in the energy equations. But convergence difficulties and a slow computing speed are the limitations of this model, because the CFX-4 code adapts a segregated solver to resolve a moderator circulation including a strong coupled-effect. Compared to a segregated solver, a coupled-solver is highly efficient and robust especially for a flow with a strong interference between the variables such as combustion.

In this study, the developed moderator analysis model based on CFX-4 is transformed into a new moderator analysis model based on CFX-10(ANSYS Inc.) that adapts a coupled solver. The new model for a CANDU moderator analysis, CFX10-CAMO, is examined and its results are compared with the former results. For Wolsong Units 2/3/4, a steady-state moderator circulation under operating conditions and a local moderator subcooling during a LOCA transient were calculated using the developed CFD tool.

2. Steady-State CANDU Moderator Circulation

For the moderator analysis of Wolsong NPP Units 2/3/4, the spatial heat distribution of the core region is calculated based on the actual core power map. To reduce the discretization error in the reflector region, butterfly-shaped grid structures (Carlucci et al. [2]) are selected. The butterfly-shaped grid structures allow for finer cells in the reflector region rather than in the core region. This structured hexahedral grid has 113,088 nodes in the core region and 183,696 nodes in the reflector region. The y^+ values at the near wall nodes are in the range of 10 ~ 300.

The steady state computation using CFX-10 was performed in a Pentium IV CPU. The energy imbalances were checked for a convergence. The total CPU time for the RMS residuals to reach a convergence criterion of 10^{-4} was 15 hour 3 min 31 sec, which is about 10 times faster than the case of a segregated solver (CFX-4).

Under normal operating conditions, the calculated maximum temperature of the moderator is 81.1 ^{o}C at the upper center region of the core, which corresponds to a minimum subcooling of 26.5 ^{o}C. Figure 1 shows the temperature distributions for the normal operating conditions. A jet reversal occurs at an angle of about 50^o over the horizontal centerline and the hottest spot is located at the upper center area of the core region, which slightly tilts to one side from the vertical centerline.

3. Transient Calculations for DBA's

For the transient moderator analysis, the bundle heat load data from multiple single channel analyses by thermal-hydraulic codes such as CATHENA or CHAN should be applied to the source terms of the energy equations. FORTRAN subroutines (so called "Junction Box Routine" in CFX-10) are written, compiled and linked with the solver. Figure 2 shows the relationship between the solving procedure and the user FORTRAN subroutine. Three user subroutines are used. Firstly, the heat load data is read from the input files and stored. Secondly, the transient time information for each time step is obtained from the solver. And finally, the bundle heat loads to the moderator are implemented into each control volume according to the correspondence between the bundle locations and the vertex coordinates.

A 35% RIH(Reactor Inlet Header) break with a loss of ECC(Emergency Core Cooling) injection was selected for the transient analysis, in which the power to the moderator following PT/CT contacts is higher than the other LOCA's. The spatial distribution of a direct heating is assumed to follow the operating power distribution. The PT/CT contact heat transfer occurs at various locations at different times according to the results of the fuel channel analyses by CATHENA and CHAN-IIA.

The moderator heat load curve has three distinct humps, which are due to the LOCA power pulse(~1 sec), the PT/CT contacts of the critical pass during the Blowdown Phase(0~40 sec), and the PT/CT contacts of the broken loop during the Post-Blowdown Phase(after 40 sec). The overall moderator temperature hardly changes during the LOCA power pulse at about 1 sec, due to a relatively short time period. Due to PT/CT contacts, the flow field and the temperature distribution after 20 sec experiences some local changes. However, the flow pattern remains about the same as the steady-state flow pattern.

Figure 3 is a plot of a local minimum subcooling of the horizontal plane at a depth of the 5 selected channel rows. The local subcooling at the depths of the A and D rows of this analysis and Collins[3] are well matched with each other, even though their resultant flow fields show some differences. Because Yoon et al.[1] showed that the minimum moderator subcooling continued to decrease after 200 sec from a LOCA initiation, this transient calculation was performed until 200 sec.

4. Conclusion

A CFD moderator analysis model was developed by using a coupled solver, which was found to be more effective and faster than a segregated solver. The computing time was reduced by more than 10 times. For a transient moderator analysis during LOCA events, FORTRAN subroutines were developed for the implementation of a time-dependent bundle heat load to the moderator. For a 35% RIH break with a loss of ECC injection, a transient moderator analysis was performed and the resultant minimum subcooling was estimated.

Acknowledgement

This project has been carried out under the Nuclear R&D Program by MOST.

REFERENCES

[1] C. Yoon, B.W. Rhee, H.T. Kim, J.H. Park, and B.-J. Min, "Moderator Analysis of Wolsong Units 2/3/4 for the 35% Reactor Inlet Header Break with a Loss of Emergency Core Cooling Injection," *J. of Nuclear Science and Technology*, Vol. 43, No. 5 (2006)

[2] L.N. Carlucci, V. Agranat, G.M. Waddington, H.F. Khartabil and J. Zhang, Validation of the MODTURC_CLAS Moderator Circulation Code for CANDU 9 Steady-State and Transient Conditions, *21st CNS Nuclear Simulation Symposium*, Ottawa, Sept. 24-26 (2000)

[3] W.M. Collins, PHOENICS2 Model Report for Wolsong 2/3/4 Moderator Circulation Analysis, 86-03500-AR-053, (1995)

[4] Wolsong Units 2/3/4 Final Safety Analysis Report, Chap. 15.3.1.1.C, KOPEC (1995)

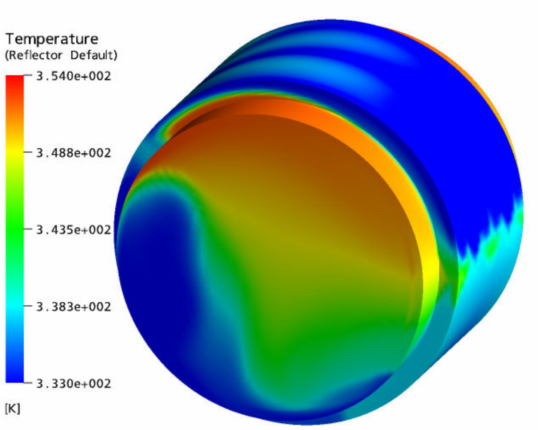

Figure 1. Steady-state moderator temperature of the Wolsong Units 2/3/4

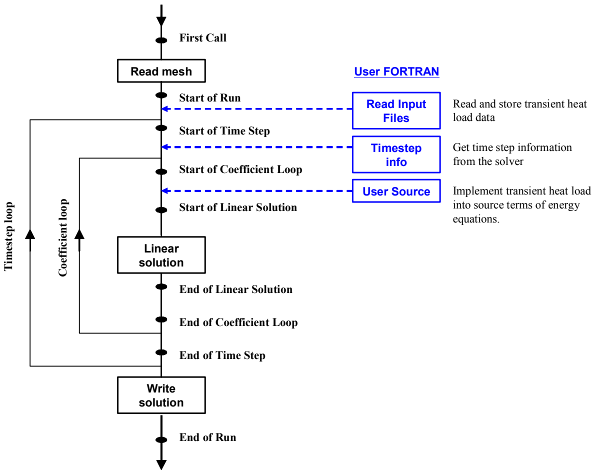

Figure 2. Transient computing procedure and user FORTRAN subroutines

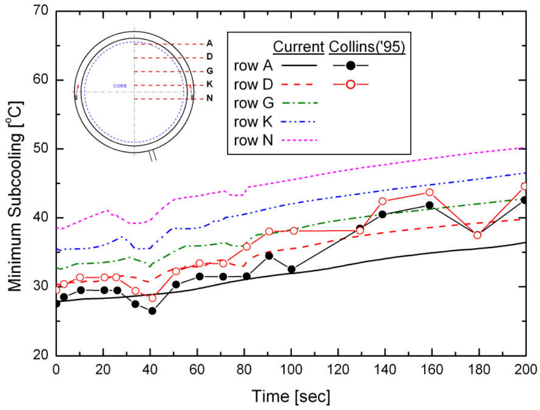

Figure 3. Minimum subcooling from CFX-10 moderator analysis for 35% RIH with loss of ECC injection