A Multi-Physics simulation of the Reactor Core using CUPID/MASTER

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1. Introduction

KAERI has been developing a component-scale thermal hydraulics code, CUPID. The aim of the code is for multi-dimensional, multi-physics and multi-scale thermal hydraulics analysis. In our previous papers, the CUPID code has proved to be able to reproduce multi-dimensional thermal hydraulic analysis by validated with various conceptual problems and experimental data [1]. For the numerical closure, it adopts a three-dimensional, transient, two-phase and three-field model, and includes physical models and correlations of the interfacial mass, momentum, and energy transfer. For the multi-scale analysis, the CUPID is on progress to merge into system-scale thermal hydraulic code, MARS [2].

In the present paper, a multi-physics simulation was performed by coupling the CUPID with three dimensional neutron kinetics code, MASTER. The MASTER is merged into the CUPID as a dynamic link library (DLL). The APR1400 reactor core during control rod drop/ejection accident was simulated as an example by adopting a porous media approach to employ fuel assembly. The following sections present the numerical modeling for the reactor core, coupling of the kinetics code, and the simulation results.

2. Numerical Methodology

2.1 Reactor Core modeling

For a better estimation of this simulation, the reactor vessel of APR1400 was employed. In this calculation, only the fuel assembly and their outer reflector area were modeled [3]. To simulate the two-phase flow in the fuel assembly region, a porous media approach was adopted. The porosity of the fuel assembly region is at about 0.54 and the permeability at horizontal direction within the porous media is assumed to be unity, whereas the permeability at axial direction to be same as porosity. The reflector region was also treated as another porous zone with the arbitrary porosity necessary to control the inlet mass flux by targeting 5% of the total inlet mass.

2.2 3D kinetics code coupling

Fig. 1 shows the correlation among the hydrodynamic model (HDM), heat structure model (HSM) and reactor kinetics model (RKM). The RKM calculates the core power and trasnfers to RKM. Meanwhile, the HDM and HSM provides moderator's density and fuel rod's temperature, respectively.

The coupling procedure between the CUPID and MASTER was easily achieved as similar as one for the MARS/MASTER coupling [4]. At first, the MASTER was convertied into a Dynamic Link Library (DLL). And then, the CUPID calls the MASTER DLL and calculates the heat source prior to calculating the HSM. An information between two code is accomplished by DLL arguments and it includes;

- CUPID-to-MASTER: moderator's temprature and density, fuel rod's temperature, control rod's location, boron's concentration
- MASTER-to-CUPID: overall core power and local power

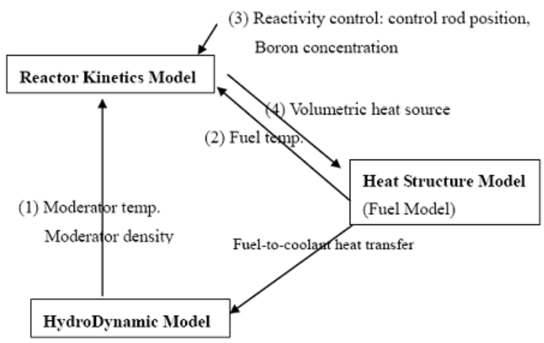
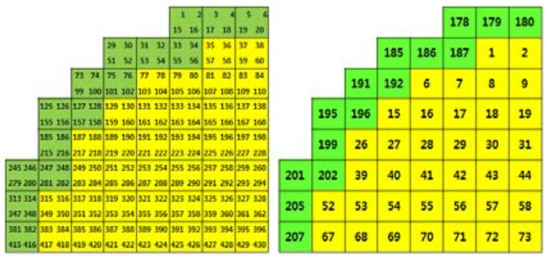


Fig.1. Link diagram for thermal hydraulics model and reactor kinetics model [4]

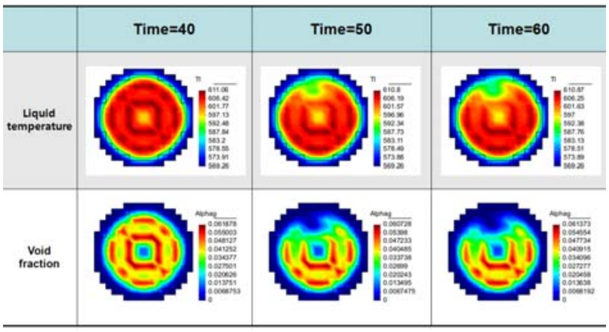
Since the sizes of the computational cell are different between CUPID and MASER, a method for cell mapping should be established. Fig. 2 shows the computational cell for both codes. The MASTER has 4 calculation cells for each fuel assembly, whereas the CUPID employs one cell for each fuel assembly by adopting the porous media approach.



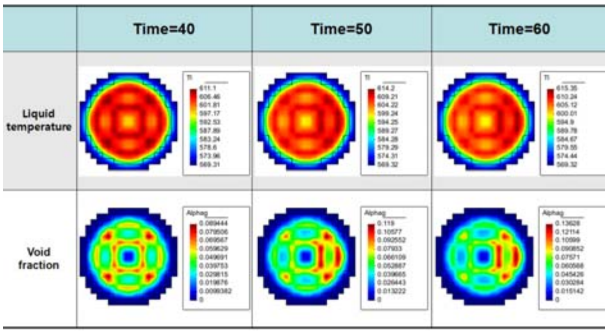
(a) MASTER (b) CUPID
Fig. 2. Computational cell for MASTER and CUPID

3. Result and Discussion

Among the reactivity induced transients, a control rod's drop/ejection accident was considered. Fig. 3 shows the contours of liquid velocity and void fraction at the outlet for both CEA drop and ejection accidents. Fig. 5 shows the time history of the liquid temperature and void fraction at which they are locally maxima for both accidents. At first, the calculation for a steady state condition has been carried out up to 40 sec. During the steady state calculation, the heat generation from the MASTER is assumed to be constant. Initially the axial heat generation profile of MATER shows local maxima at the upper and lower regions, and appears as a parabolic profile between the two peaks. And also, the radial distribution of the core power shows an annulus shape regardless of the axial position.



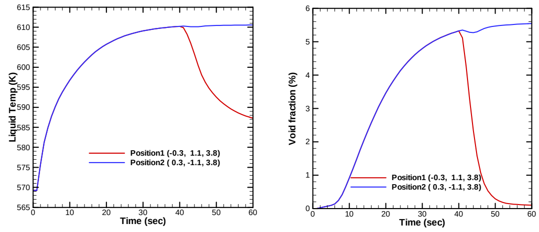
(a) CEA25 drop accident



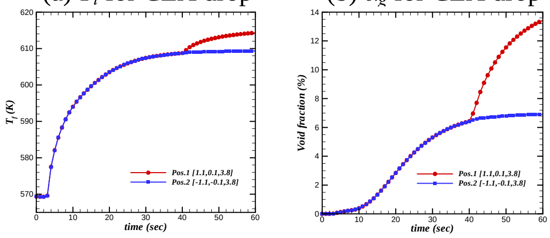
(b) CEA51 ejection accident

Fig. 3 Contours of liquid temperature and void fraction for both CEA drop/ejection accident

Transient is assumed to start at 40s when the steady state condition has reached. For CEA drop accident, the CEA25 is assumed to drop in 4.2 sec. And then, the local liquid temperature and void fraction near that position are supposed to be decreased as shown in the Fig 4(a) & (b). On the other hand, the ejection accident, the CEA51 is assumed to be ejected immediately. Since the control rod is assumed to be ejected during normal operation, the total core power is observed to be only 10% and liquid temperature to be 5 K larger than those for normal operation. The void fraction, nonetheless, is observed to be twice larger than that of normal operation as shown in the Fig. 4 (c) & (d).



(a) T_l for CEA drop (b) α_g for CEA drop



(a) T_l for CEA ejection (b) α_g for CEA ejection

Fig. 4 Time-history of liquid temperature and void fraction for both CEA drop/ejection accidents

4. Conclusions

In this study, a multi-physics simulation of thermal hydraulics and neutron kinetics was attempted. The component thermal hydraulic analysis code CUPID was coupled with a 3D neutron kinetics code, MASTER, using a dynamic link library (DLL) feature. The simulation results for the control rod's drop/ejection accident of the APR1400 reactor core showed that the multi-dimensional, multi-physics analysis was successfully performed. However, further improvement of the physical models, such as a wall friction factor, turbulent diffusion coefficient, are required for a more realistic simulation of the reactor core.

Acknowledgement

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