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Preliminary Development of the MARS/FREK Spatial Kinetics Coupled System Code for Square Fueled Fast Reactor Applications

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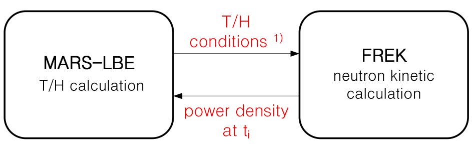
1. Introduction

Incorporation of a three-dimensional (3-D) reactor kinetics model into a system thermal-hydraulic (T/H) code enhances the capability to perform realistic analyses of the core neutronic behavior and the plant system dynamics which are coupled each other. For this advantage, several coupled system T/H and spatial kinetics codes, such as RELAP/PARCS, RELAP5/PANBOX, and MARS/MASTER have been developed. These codes, however, so far limited to LWR applications. The objective of this work is to develop such a coupled code for fast reactor applications. Particularly, applications to lead-bismuth eutectic (LBE) cooled fast reactor are of interest which employ open square lattices. A fast reactor kinetics code applicable to square fueled cores called FREK is coupled the LBE version of the MARS code. The MARS/MASTER[1] coupled code is used as the reference for the integration. The coupled code MARS/FREK is examined for a conceptual reactor called P-DEMO[2] which is being developed by NUTRECK. In order to check the validity of the coupled code, however, the OECD MSLB benchmark exercise III calculation is solved first.

2. Development and Verification

To analyze the core neutronic behavior, it is required to consider the thermal feedback effect on the group constants. The core T/H parameters such as the coolant density and effective fuel temperature of each node need to be determined at each time step by a T/H calculation module which is MARS in our case. The T/H conditions transferred from MARS to FREK are then used for the group constant update and a new power distribution and the total power (Watts) are obtained by FREK. This information is then sent back to MARS for the T/H calculation at the next step. The data transfer scheme is shown in Fig 1.



1) coolant density and temperature, fuel center and surface temperature

Fig 1. Coupling Algorithm

To perform the coupled calculation, a mapping between T-H and neutronics nodes is required. In general, the neutronics nodes are larger than the T/H ones as shown in Fig.2 because the coupling between nodes is stronger for neutron transport than T/H flow.

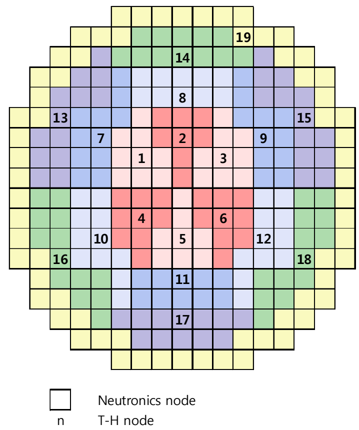


Fig 2. Neutonic and T-H nodes of the TMI-1 Core

The coupling of MARS and FREK can be achieved using the dynamic link library (DLL) [3]. The newly written link subroutines for mapping between T-H and neutronic nodes and data exchange between MARS and FREK are added to a DLL, FREK.dll. The driver code, MARS, calls FREK with a different indication of the calculation mode: initialization, steady-state calculation, or transient-state calculation.

In order to verify the validity of MARS/FREK, the OECD MSLB (main steam line break) benchmark exercise III was solved. The transient occurs by a double ended break in a 24” steam line and a slot break in an 8” pressure balance line. The transient was analyzed for 100 seconds with the time step size of 0.1 seconds. For the system T/H calculation by MARS, the MARS model made by KAERI was used. The MARS/FREK result for the initial steady-state gives the effective multiplication factor (k_{eff}) of 1.00776 which is almost identical to that of MARS/MASTER. As shown in Fig.3, the total core power behavior of MARS/FREK essentially coincides with that of MARS/MASTER. This good agreement indicates that the coupling was properly performed and the multigroup kinetics module of FREK works fine for the two-group case as well.

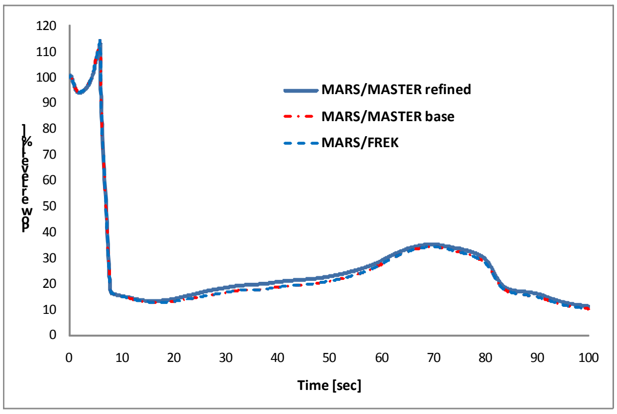


Fig 3. Total Core Power Behaviors

3. Application to P-DEMO

The system T/H analysis of P-DEMO was performed using a MARS 1-D model [4]. To analyze asymmetric flow transients, the P-DEMO core was nodalized with 8 core channels and 1 reflector channel as shown in Fig.4.

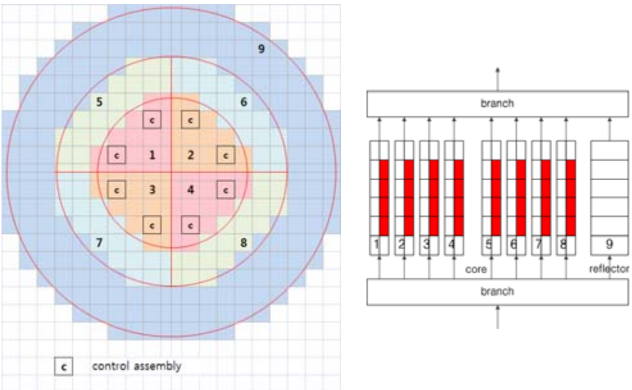


Fig 4. T/H Nodalization of the P-DEMO Core

In order to check the validity of the MARS input for the coupled calculation, the result of MARS/FREK was first compared with that of the MARS stand-alone calculation. The inlet/outlet temperatures of the MARS stand-alone and MARS/FREK were 545.33K/697.02K, and 545.31K/697.27K, respectively, in steady-state calculation. So it was confirmed that the coupling scheme is proper. The effective multiplication factor (k_{eff}) obtained from MARS/FREK was 1.01486.

To assess the asymmetric calculation capability, the coupling calculation with a rodded core was performed. One of the two control assemblies in Channel 1 was inserted while the others were all withdrawn. In this case, the effective multiplication factor (k_{eff}) drops to 1.00320. As shown in Table I, the power of the rodded Channel 1 was decreased as expected. As a result, the outlet temperature and mass flow rate of Channel 1 were also decreased. This reasonable result verifies the asymmetric calculation capability available by MARS/FREK.

Table I. Comparison between Unrodded and Asymmetrically Rodded Core Calculations

	Power (MW)		Outlet temp. (K)		Mass Flow (kg/s)	
chan.	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	13.35	9.58	793.14	781.30	373.57	281.29
2	13.35	12.12	793.14	788.12	373.57	346.07
3	13.35	14.92	793.14	796.48	373.57	412.07
4	13.35	15.80	793.14	799.22	373.57	431.57
5	11.65	7.88	788.20	777.20	332.44	235.39
6	11.65	10.81	788.20	784.42	332.44	313.27
7	11.65	13.95	788.20	793.44	332.44	389.99
8	11.65	14.93	788.20	796.44	332.44	412.41

*Case 1 : Unrodded core calc. / Case 2 : Rodded core calc.
*Total Power : $100MW_{th}$

4. Conclusions

A coupled system T/H and 3-D neutron kinetics code for square fueled fast reactors, MARS/FREK has been developed using the dynamic link library (DLL) on Windows operating system. The test results for the OECD MSLB Exercise III benchmark show very good agreement with those of MARS/MASTER which confirms sound coupling and the multigroup kinetics capability of FREK.

The practical application to the steady-state calculations of the P-DEMO core results in the same temperature distribution as the standalone run for the symmetric core which indicates the correct coupling as well. The multi-channel model for the asymmetrically rodded core yields reasonable asymmetrical temperature files. More extensive verification of the transient solution and incorporation of the feedback mechanisms for the fast reactors are underway.

Acknowledgements

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