Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

Development of the Dynamic Test Bed of JRTR Based on MARS

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1. Introduction

KAERI has been developing the simulator for the JRTR (Jordan Research & Training Reactor) based on the best-estimate code, MARS for the purpose of operator training. The JRTR simulator is also used as a dynamic test bed (DTB) to validate the control logics in RRS (reactor regulating system), which is under development. In the previous study [1], we have developed the PCS (primary coolant system) model of JRTR in batch mode. In this study, the MARS code has been integrated into simulator environment. To be used as a DTB for validating the RRS, a reactor kinetics model is an essential part. Althrough the MARS code has a point kinetics model, it lacks the xenon reactivity model. Therefore, we have also developed the iodine-xenon transient model for the DTB test.

2. Model Development

2.1 JRTR PCS Model

Development of the JRTR primary cooling system (PCS) model is described in the previous study [1]. It consists of the reactor core and the related pool cooling systems. Fig. 1 shows the overall layout of the MARS model for the JRTR. The red symbols in the figure represent the interface time-dependent volumes between the MARS and 3KeyMaster [2]. Minimum connnections between two modules have been completed until now because most of the interfaces are not required in the DTB test.

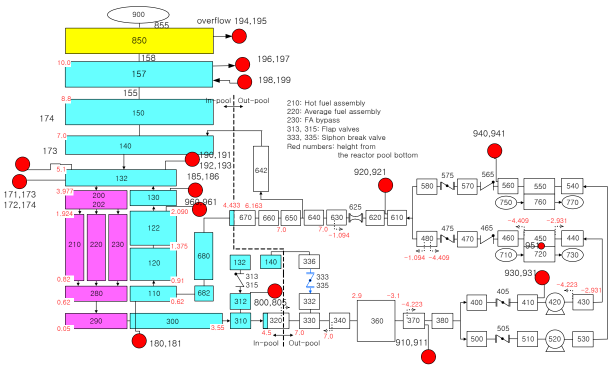

Fig. 1. MARS nodalization for JRTR

2.2 MARS-3KeyMaster Interface Functions

The interface functions between the MARS and 3KeyMaster are required to simulate plant operation. With ViSA [3] interface feature, it is possible to transfer the variables to the other side. The general concept of variable interface between the MARS and 3KeyMaster is shown in Fig. 2.

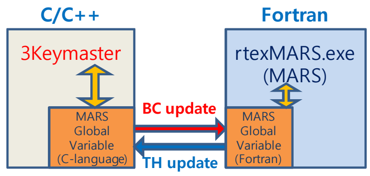

Fig. 2. Variable interface function

2.3 Point Kinetics Model

The delayed neutron data is summarized in Table I. The number of the delayed neutron groups in the MARS code is fixed to 6. Therefore, we used delayed neutron data only and neglected the photoneutron data. The effective delayed neutron fraction, β_{eff} is 0.00685.

Table I: Decay constant and yield of delayed neutron

Group	1	2	3	4	5	6
λ_i (1/s)	0.0125	0.0317	0.1090	0.3170	1.350	8.730
γ_i (%)	3.2	16.8	16.4	45.6	13.3	4.7

The reactivity model of the MARS is as follows:

$$r(t) = r_o - r_B + \sum_{i=1}^{Ns} r_{si}(t) + \sum_{i=1}^{Nc} r_{ci}(t) + r_{fb}(t) \qquad (1)$$

$r_o, r_B, r_{si}(t), r_{ci}(t)$ and $r_{fb}(t)$ are an initial reactivity, bias reactivity, input table reactivity, control variable reactivity and feedback reactivity, respectively. As shown in Eq. (1), there is no explicit xenon posion effect in MARS reactivity model. Therefore, xenon transient model has been incorporated into the MARS code. An iodine-xenon kinetics model is as follows [4]:

$$\begin{aligned} \frac{d\hat{I}}{dt} &= \lambda_I\left(\hat{N} - \hat{I}\right) \\ \frac{d\hat{X}}{dt} &= \frac{\lambda_X + \lambda_e}{\gamma_X + \gamma_I}\left(\gamma_X \hat{N} + \gamma_I \hat{I}\right) - \left(\lambda_e \hat{N} + \lambda_X\right)\hat{X} \end{aligned} \qquad (2)$$

$\hat{I}, \hat{X}, \hat{N}, \lambda_X, \lambda_I, \lambda_e, \gamma_X$ and γ_I are normalized iodine, xenon and neutron population, decay constant of iodine and xenon, effective decay constant of xenon, yield fraction of xenon and iodine, respectively. Eq. (2) is solved by the 2nd order Runge-Kutta method. The values of all constants in Eq. (2) are based on the reference [4].

Rod worth is the most important factor in the DTB test because of its large reactivity. There are four CARs (control absorber rods) in the JRTR. The CAR worth is simulated by a control variable reactivity (r_{ci}) in Eq. (1). Once the RRS control logics in 3KeyMaster determine each CAR position, MARS will calculate the each CAR worth by using a tabular relationship between position and worth as shown in Fig. 3. Currently, critical rod position is assumed to be 430 mm from the bottom of the core.

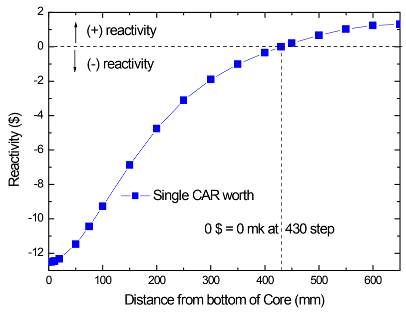

Fig. 3 CAR position vs. intergral CAR worth

3. Simulation Results

To verify the capability of the DTB model, two kinds of tests were conducted. The first one is a rod insertion test without xenon to verify the CAR worth model and the second one is a reactor trip test with the equilibrium xenon to verify the iodine-xenon transient model.

In a rod insertion test, the single CAR is inserted into the core slightly (-1 mm) to change the CAR worth (-0.011$). In a reactor trip test, all CARs are fully inserted into the core instantly to decrease fission power to almost zero.

Fig. 4 shows the result of a rod insertion test. The fission power starts to decrease promptly as soon as a CAR is inserted into core and decreases continuously until the feedback reactivities compensate the CAR worth.

The normalized xenon and iodine concentrations during a reactor trip test are plotted in Fig. 5. As fission power decreases due to CAR full insertion, xenon concentration increases whereas iodine concentraion decreases. The maximum xenon concentration occurs around 10 hours after trip and its maximum value is almost three times of the equilibrium concentration. This result is consistent with the theorical value. After 10 hours, the xenon concen-tration decreases graudually.

Fig. 6 shows the comparison of a real time and a computational time during a reactor trip test. As shown in figure, two times are identical until the end of a simulation. Therefore, the DTB model can satisfy the basic requirement of the real-time calculation for the simulator.

4. Conclusions

A point kinetics model for the DTB of JRTR has been developed and merged into the simulator environment. Through several verification tests, it is found that the iodine-xenon transient model has been incorporated into the MARS successfully and the CAR worth model also works in proper way. In addition, the capability of real-time calculation was also verified in these tests. Consequently, it is concluded that the developed PCS model with modified point kinetics can be used in the full-scope simulator for the JRTR if all the interfaces are connected to 3KeyMaster.

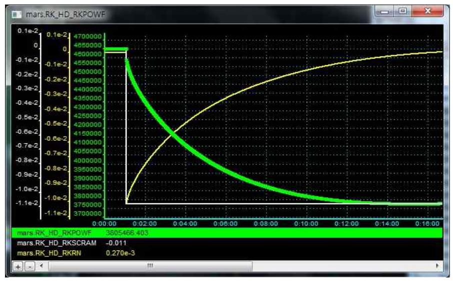

Fig. 4 CAR worth (white), total reactivity (yellow) and fission power (green)

Fig. 5 Iodine (green) and xenon (white) concentration

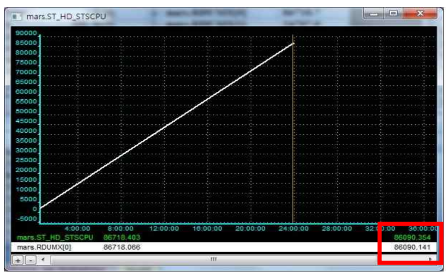

Fig. 6 Real (green) and computational (white) time

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