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MARS Simulation of the Steady-State and Transient Void Behaviors in an 8x8 Rod Bundle

J. J. Jeong*, D. H. Hwang and B. D. Chung
Korea Atomic Energy Research Institute, Dukjin 150, Yuseong, 305-353 Daejeon
*E-mail: jjjeong@kaeri.re.kr

1. Introduction

The MARS code is a best-estimate multi-dimensional thermal-hydraulic system code. The three-dimensional (3-D) reactor vessel module of MARS has a subchannel flow mixing model [1]. It has been assessed against various experimental data and, using the results of the assessment, a simple modification of the subchannel flow mixing model was suggested to take into account the effects of the system pressure on the void drift phenomena.

In this paper, the steady-state and transient void distributions in the NUPEC 8x8 rod bundle [2, 3] are simulated using the modified subchannel flow mixing model of the MARS 3-D module.

2. Test Facility and the MARS Input Model

The NUPEC 8x8 rod bundle test facility has a full range of steady-state test capability under typical BWR operating conditions and can also simulate unsteady characteristics of operational transients. The full-scale BWR simulated fuel assembly of an 8x8 rod bundle was installed in the test facility. The heated length of the rod bundle is 3.708 m.

Two kinds of void distribution measurement systems, X-ray CT scanner and X-ray densitometer were used [2]. Void distributions were measured in fine-mesh using the X-ray CT scanner at a point 50 mm above the heated zone under steady-state cases. In order to avoid the effect of the two-phase flow fluctuations, the collection of projection data was repeated and the results were time-averaged. The attained spatial resolution was as small as 0.3 mm × 0.3 mm. Three X-ray densitometers (DM) were used to measure cross-sectional average void fractions during transients, which are located at the axial locations 0.682 m, 1.706 m, and 2.730 m above the bottom of the heated section.

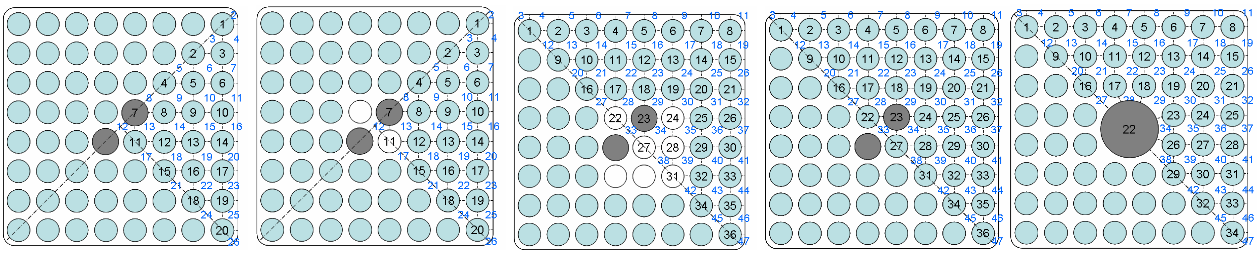
Five different types of bundle assembly design with different combinations of geometries and power shapes were tested in the steady-state void distribution experiments.

Transient tests were performed to measure the cross-sectional averaged transient void fraction over a range of pressure, flow, and power variations. Experiments for the four operational transients were carried out. In this work, turbine trip without bypass and one pump trip were simulated.

The fuel assembly types and the MARS input models are depicted in Fig. 1. For the transient benchmark, Assembly Type 4 was used. For the MARS input model, 1/2 or 1/4 radial symmetry assumptions, depending on the bundle geometry and radial power distributions, were used for a computational efficiency. 24 axial equal-length meshes were used for the heated region.

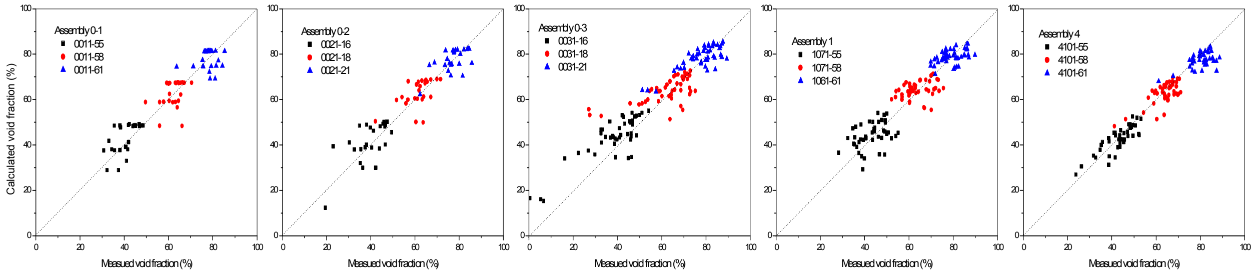
3. The Results of the MARS Simulation

Among the various steady-state tests with different fuel assemblies, 15 tests (i.e., 3 tests for each of 5 fuel assembly types) were used for this assessment. The steady-state subchannel void distributions above the top end of the heated region are compared in Fig. 2. The MARS results show very good agreements with the experimental data. In general, the effect of non-uniform radial power distribution is reasonably represented by the MARS code. As for the transient benchmark, the boundary conditions for the turbine and pump trip are illustrated in Fig. 3. The resulting transient void behaviors are shown in Fig. 4. Transient behaviors are captured very well by the MARS code in spite of some errors in the initial conditions.



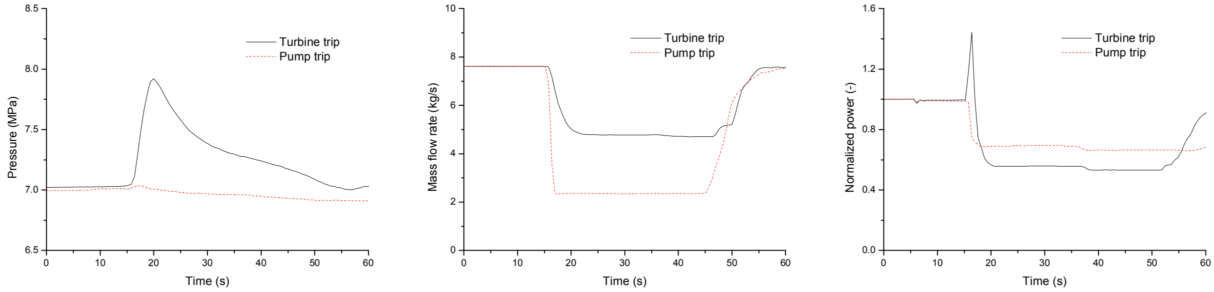
(a) Type 0-1 (b) Type 0-2 (c) Type 0-3 (d) Type 1 (e) Type 4

Figure 1. The fuel assembly type and its MARS input model: Channel and rod numbers are given.



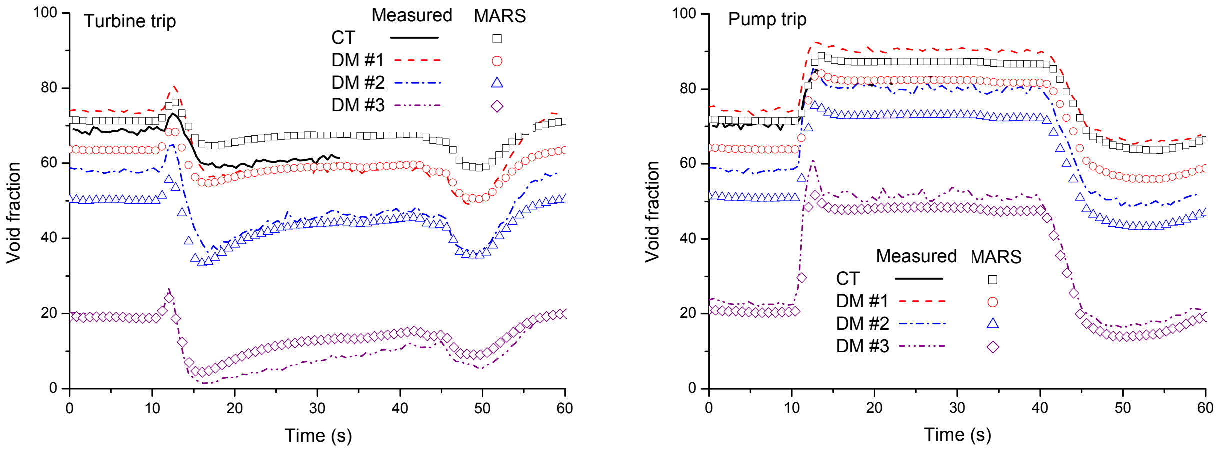
(a) Type 0-1 (b) Type 0-2 (c) Type 0-3 (d) Type 1 (e) Type 4

Figure 2. Comparison of the steady-state void fractions at the subchannels above the channel exit.



(a) Exit pressure vs. time (b) Inlet mass flow rate vs. time (c) Normalized power vs. time

Figure 3. Boundary conditions for the turbine trip and the pump trip.



(a) Turbine trip scenario (b) Pump trip scenario

Figure 4. Comparison of the transient void fractions: Turbine and pump trip cases

4. Concluding Remarks

The subchannel mixing model of the MARS 3-D module was assessed using the 8x8 rod bundle test data. The results of the assessment showed that MARS can predict the subchannel void distributions very well. The average and the standard deviation of the P/M of the subchannel void fractions decreased as the void fraction increases. The simulation results of Assembly Type 4 showed that the effect of a non-uniform radial power distribution can be represented very well by MARS. In addition, it was shown that MARS can predict transient behaviors very well in spite of some errors in the initial conditions.

References

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