Validation of WIMS-IST/RFSP and MCNP Codes Using DCA Experiments

Byung Joo Min
Korea Atomic Energy Research Institute
P.O.Box 105, Yusong, Daejeon 305-600, Korea
E-mail bjmin@kaeri.re.kr

1. Introduction

The physics analysis of the Canadian deuterium uranium (CANDU) reactor has been typically performed by the diffusion code RFSP using lattice-cell properties generated by the lattice code WIMS-IST (WIMS). The development of the advanced CANDU reactor (ACR-700) necessitates new validation activities for the reactor analysis codes. Therefore, the validation of WIMS/RFSP code system using criticality measurement data of the deuterium critical assembly (DCA) has been conducted. Also the calculations reported here include the MCNP-4C (MCNP) code, which is widely used as a computational benchmarking tool for the system of which the experimental data are not available.

This study revisits the measured data of DCA experiments to investigate the accuracy of WIMS/RFSP and MCNP codes for predicting the criticality and void reactivity, which are considered to be the most important physics parameters of the CANDU reactor.

2. The Calculation Models of DCA Core

The measurement data of DCA include the criticality, void reactivity, reaction rate ratio, power profiles, etc., of which results have been published in various articles. The benchmark calculations have been performed for DCA core with a lattice pitch of 22.5 cm. The uniform core is loaded with 1.2 wt% UO_2 fuels.

2.1 Model of the WIMS-IST Code

In the WIMS calculation, the fuel assembly was modeled as an infinite lattice, including fuel pellet, clad, coolant, pressure tube, air gap, calandria tube and a moderator. For convenience, the air gap between the fuel pellet and clad was not modeled explicitly but smeared into the clad by reducing the clad (aluminum) density. The transport calculation was performed by the collision probability (PIJ) option using the 89-group ENDF/B-VI cross-section library. The cell-average lattice parameters are collapsed into two energy groups using effective cell-average neutron fluxes. The effective neutron flux was obtained by critical buckling, which was given as experimental buckling. Because the active fuel section (moderated fuel region) is about one half of the actual fuel height, the axial leakage effect is much greater than the radial one in the DCA core. For example, the radial and axial geometric buckling is approximately 2.48×10^{-4} and 8.59×10^{-4} cm^{-2}, respectively. Therefore importance was given to the axial buckling when generating the cell-average lattice parameters using the critical buckling. The lattice parameters of the heavy water moderator were taken from the fuel lattice calculation. The lattice parameters of the non-fuel material such as grid plate, aluminum tube, B_4C absorber, etc. were also generated using the critical axial buckling. The bare fuel part is represented the model by incremental cross sections, which a difference between the WIMS case with and without moderator.

2.2 Model of the RFSP Code

In the RFSP calculation, the reactor core was modeled using a rectangular mesh structure. The core model includes 121 fuel channels, a heavy water reflector and aluminum tank in the radial direction. Below the active fuel region, the low grid plate, B_4C absorber, aluminum spacer and steel base are modeled as plates. Above the active core region, the fuel end plate, empty aluminum tube and support/grid plate are modeled.

About the boundary condition, the reference core model uses the rectangular mesh structure to describe the core boundary surrounded by the aluminum tank.

The input models are summarized as follows:

- The reference mesh sizes of the active core region are 11.25 cm and 10 cm in the radial (XY) and axial (Z) directions, respectively.
- The reference fuel type is 1.2 wt% UO_2. The bare fuel and structure materials are represented by the incremental cross section, which is defined as the difference between the macroscopic cross sections of the nominal and perturbed lattices.
- The aluminum tank was modeled in the rectangular geometry by conserving the total volume.

2.3 Model of the MCNP Code

For the MCNP calculation, the DCA core was modeled using a three-dimensional quarter core model in the radial direction. The fuel rods, cladding, fuel gap, pressure tube and calandria tubes are modeled explicitly for every fuel channel. However, the guide tubes, spacer grids and others for the safety rods are neglected. Three input cards are used to expand a fuel lattice in to the core including all fuel rods: the lattice card (LAT) is used to define an infinite array of all hexahedra or hexagonal prisms, the universe card (U) is used to specify a universe to which a cell belongs and the fill card (FILL) is used to specify a universe with which a cell is filled. The MCNP calculations were performed with 20000 particles per cycle and 2600 active cycles after 100 inactive cycles, which is sufficient for the criticality analysis. The cross-section library used for

the MCNP calculation is ENDF65MT-AECL in this study.

3. Results

The results of criticality for the nominal and voided core are summarized at Table I. The calculated effective multiplication factors of WIMS/RFSP and MCNP are 1.00663 and 0.99901, respectively. The criticality calculation by the MCNP code has shown an excellent agreement for the k_{eff}.

Table I. Summary of the Criticality for the Nominal and Voided Core

Lattice Condition	Critical Water Level	WIMS-IST[10]	MCNP	WIMS/ RFSP
Nominal	97.58 (cm)	1.00396 (89g)	0.99901 ± 0.00008	1.00663
		1.00972 (2g)		
Voided	112.66 (cm)	1.00436 (89g)	0.99673 ± 0.00009	-
		1.00836 (2g)		

The coolant void reactivity is calculated by replacing the coolant with air without changing the critical heavy water level. In this study, the void reactivity (α_v) is defined as follows:

$$\alpha_V(\%) = 100 \times \left(\frac{1}{k_f} - \frac{1}{k_v} \right),$$

Where k_f and k_v are the effective multiplication factors of the nominal and voided core, respectively. The experimental coolant void reactivity is given in Table II along with calculated ones. The result of coolant void reactivity of MCNP is – 6.46 (\$) and the difference between calculated and measured values is – 0.15 (\$), which agrees well with experimental data.

Table II. Summary of the Void Reactivity Calculation
[a]Calculated –Experimental Value

Experimental Value (\$) $\beta = 0.72$	WIMS-IST (\$) (89g)		MCNP(\$)	
	Cal.	C-E[a]	Cal.	C-E[a]
-6.31±0.43	-5.185(89g)	1.125(89g)	-6.46	-0.15
	-5.097(2g)	1.213(2g)		

However, the result of the void reactivity of WIMS/RFSP code is not included in this study because the run failed to converge.

4. Conclusions

The benchmark calculations have been performed for the WIMS/RFSP and MCNP codes. This study calculated the criticality and void reactivity data of DCA for the validation of the MCNP and the RFSP calculation based on lattice parameters generated by the WIMS code. The benchmark calculation has shown following facts:

(1) In the WIMS/RFSP calculation procedure, it is appropriate to use critical buckling when calculating the effective neutron flux for the group constant condensation.
(2) The result of WIMS/RFSP, the criticality is overestimated by 0.66% δk. The coolant void reactivity is not included in this study.
(3) For the MCNP, the results show an excellent agreement with the experimental data. The multiplication factors of nominal and voided core are 0.99901 and 0.99673, respectively. Also the coolant void reactivity of MCNP is – 6.46 (\$) which agrees well with measured data.
(4) For the application of WIMS/RFSP to the Advanced CANDU reactor, it is recommended to perform more validation work based on the physics measurement data of the various fuel compositions at DCA.

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