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An Assessment of Resonance Treatment for Pin-cell Lattices in WIMS-CANDU using MCNP

Won Young Kim, Byung Joo Min and Joo Hwan Park
Korea Atomic Energy Research Institute, 150 Dukjin-Dong, Yousong-Gu, Daejourn, Korea

1. Introduction

The WIMS-CANDU is a lattice code which considers a depletion capability for the analysis of reactor physics problems related to a design and safety. The WIMS-CANDU code has been developed from the WIMSD-5B code, a version of the WIMS code released from the OECD/NEA Data Bank in 1998. The lattice code POWDERPUFS-V has been used for the physics design and analysis of natural uranium CANDU fuel. However, since the application of POWDERPUFS-V is limited to the fresh natural uranium fuel due to its empirical correlations, the WIMS-AECL code has been developed by AECL to substitute the POWDERPUFS-V and has been used for the advanced CANDU fuel design and analysis. The WIMS-CANDU code is also being developed to perform the physics analysis of the present operating CANDU reactors as a replacement of POWDERPUFS-V.

The purpose of this study is to assess the resonance treatment implemented in WIMS-CANDU for the pin-cell lattices using a Monte Carlo code MCNP and an experimental data. The resonance treatment in WIMS-CANDU was implemented on the basis of the method developed by Stamm'ler. To perform the benchmark calculation using the MCNP code and the WIMS-CANDU code, the new cross-section libraries were generated from the evaluated nuclear data file (ENDF) version VI. In the case of the WIMS-CANDU code, the library has the 69-energy group distribution. The physics parameters such as the multiplication factors and reaction rates were calculated by both of WIMS-CANDU and MCNP and these were compared with experimental data. The results show that the physics parameters calculated by WIMS-CANDU are consistent with those of MCNP and experiment data except ρ^{28}.(The ratio of capture reactions in U^{238} above 0.625eV to those below 0.625eV) for the pin-cell lattices.

2. Resonance treatment in WIMS-CANDU

The resonance treatment implemented in WIMS-CANDU is based on the treatment developed by Stamm'ler. The resonance treatment uses the intermediate resonance approximation to calculate the group-averaged resonance integral as a function of the background scattering cross-section. And an equivalence relation is used to account for the heterogeneous geometry in reactor lattices. The effective resonance integrals are obtained by the interpolation from tables of homogeneous resonance integrals in the data library.

In the Stamm'ler approximation, Carlvik's two-term rational expression is used for the lethargy-dependent single cylindrical rod self-collision probability $\boldsymbol{p_{ff}}(u)$:

$$\boldsymbol{p_{ff}}(u) = 2x/(x+2) - x/(x+3),\ x = 4V_f\Sigma_f(u)/S_f.$$

The lethargy-dependent fuel-to-fuel collision probability $\boldsymbol{p_{FF}}(u)$ for an infinite lattice of pin cells is related to the single-rod self-collision probability $\boldsymbol{p_{ff}}(u)$ by

$$\boldsymbol{p_{FF}} = \boldsymbol{p_{ff}} + x(1-\boldsymbol{p_{ff}})^2 / \{x(1-\boldsymbol{p_{ff}}) + A\}$$

where $A = S(n)\gamma_b / S_f t_{fb}^2$ and $S(n)$ is the fuel cell boundary surface area. In the Stamm'ler approximation, γ_b and t_{fb} are approximated to be energy-independent within each energy group. In the RESALT subroutine of WIMS-CANDU, γ_b and t_{fb} are computed for the infinite lattice on the basis of the collision probability using the Carlvik's method. The value A gives the $\alpha_{2,1}$ and β:

$$\alpha_{2,1} = \{(5A+6) \pm \sqrt{A^2+36A+36}\}/2(A+1),$$
$$\beta = \{(4A+6)/(A+1) - \alpha_1\}/(\alpha_2 - \alpha_1).$$

By correcting the total cross-section by $\alpha_{2,1}$ and using the subroutine RESINT, the resonance integrals, the microscopic cross-sections and the effective absorption cross-sections are computed for the pin-cell infinite lattice.

3. Calculation method

In order to perform the cell-code validation of the resonance treatment for the pin-cell lattices in WIMS-CANDU, the typical benchmark problems such as TRX-1, TRX-2 and BAPL-1, BAPL-2, BAPL-3 pin-cell lattices were used, which were characterized by a simple geometry consisting of the fuel, cladding and coolant. The TRX and BAPL lattices are light water moderated simple assemblies reduced from the whole reactor operating at room temperature. The fuel materials of the TRX and BAPL lattices are 1.3wt% enriched uranium metal and uranium oxide, respectively. These lattices are modeled in a two-dimensional hexagonal geometry with the reflective boundary condition.

The pin-cell calculations were performed by the MCNP code and WIMS-CANDU code. In the case of MCNP code, the pin-cell model is not able to represent the critical state without modeling the full core and so the experimental data was compared with WIMS-CANDU, while the comparison between the WIMS-CANDU and the MCNP was conducted on the infinite pin-cell lattice model. For the cell-code benchmark calculation, the new cross-section libraries were generated for the lattice codes WIMS-CANDU and MCNP using the nuclear data file ENDF/B-VI release 3.

The WIMS-CANDU uses the library of the distribution of 69 energy groups and all MCNP calculations were performed with 3000 particles per cycle and 215 active cycles after 15 inactive cycles.

The physics parameters such as infinite multiplication factor (k_∞), effective multiplication factor (k_{eff}) and four reaction rates were calculated by the cell codes MCNP and WIMS-CANDU with the new libraries. The four reaction rates compared are as follows:

ρ^{28}: the ratio of capture reactions in U^{238} above 0.625eV to those below 0.625eV

δ^{25}: the ratio of fission reactions in U^{235} above 0.625eV to those below 0.625eV

δ^{28}: the ratio of fission reactions in U^{238} to those in U^{235}

C*: the ratio of capture reactions in U^{238} to capture reactions in U^{235}.

4. Conclusion

For the infinite pin-cell lattices, the infinite multiplication factor in the WIMS-CANDU is small compared to the MCNP results and the comparison of reaction rates indicates that δ^{28} and C* agree well within the relative difference 1.2% and 1.9%, respectively and δ^{25} within 8% on the average between MCNP and WIMS-CANDU. But the ρ^{28} show the large difference between MCNP and WIMS-CANDU. (Table 1)

For the finite pin-cell lattices, the effective multiplication factor value in WIMS-CANDU is small compared to experimental data. The comparison of reaction rates between WIMS-CANDU and experiments shows that the average differences are 3.9% for δ^{28}, 3.6% for C* and 11.5% for δ^{25}. Similarly, the ρ^{28} values show the large difference between WIMS-CANDU and experiment. (Table 2)

In the future, it is necessary to examine the absorption cross-section of U^{238} in the thermal and fast energy range in WIMS-CANDU.

Table 1 Comparison of k_{eff} and reaction rates for infinite pin-cell lattices

Lattice	Codes	k_∞	ρ^{28}	δ^{25}	δ^{28}	C*
TRX-1	MCNP	1.1766	1.3270	0.0976	0.0918	0.7913
	CANDU	1.1169	2.0114	0.1123	0.0974	0.8400
TRX-2	MCNP	1.1664	0.8650	0.0630	0.0652	0.6398
	CANDU	1.1395	1.1970	0.0664	0.0668	0.6416
BAPL-1	MCNP	1.1397	1.4310	0.0845	0.0762	0.8137
	CANDU	1.0750	2.0317	0.0914	0.0764	0.8481
BAPL-2	MCNP	1.1447	1.1650	0.0687	0.0653	0.7340
	CANDU	1.0966	1.6295	0.0732	0.0647	0.7486
BAPL-3	MCNP	1.1309	0.9206	0.0530	0.0536	0.6680
	CANDU	1.1006	1.2368	0.0557	0.0527	0.6478

* CANDU means the WIMS-CANDU code.

Table 2 Comparison of k_{eff} and reaction rates for finite pin-cell lattices

Lattice		k_{eff}	ρ^{28}	δ^{25}	δ^{28}	C*
TRX-1	EXP	0.9961	1.354	0.0994	0.0987	0.792
	CANDU	0.9644	2.087	0.1154	0.1051	0.8594
TRX-2	EXP	0.9966	0.845	0.0608	0.0713	0.651
	CANDU	0.9983	1.237	0.0678	0.0719	0.6521
BAPL-1	EXP	0.9999	1.394	0.0838	0.0762	0.809
	CANDU	0.9682	2.089	0.0936	0.0807	0.8623
BAPL-2	EXP	0.9997	1.172	0.0682	0.0656	0.736
	CANDU	0.9861	1.676	0.0749	0.0683	0.7604
BAPL-3	EXP	0.9999	0.917	0.0523	0.0538	0.657
	CANDU	0.9990	1.268	0.0566	0.0551	0.656

* CANDU means the WIMS-CANDU code.
* EXP means the experimental value.

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