A Benchmark Calculation of the Wolsong-2 Nuclear Power Plant by the Reactivity Device Model of the DRAGON code

Chang Je Park and Hangbok Choi
Korea Atomic Energy Research Institute, P.O. Box 105, Yuseong, Daejeon, 305-600, Korea
cjpark@kaeri.re.kr

1. Introduction

Advanced physics codes have been developed and used for the design of new CANDU fuels such as the low-enriched uranium, mixed oxide fuel, thorium fuel and the DUPIC fuel [1-3]. Among the advanced physics codes, WIMS-AECL is the most widely used for the CANDU fuel lattice analysis owing to its capability of modeling a two-dimensional lattice and diverse isotopic data of the cross-section library. The WIMS-AECL provides homogenized cross-sections of the fuel lattice as well as the isotopic content of a fuel as a function of the fuel burnup. For the modeling of reactivity devices in the CANDU reactor, the SHETAN code has been used to maintain a consistency within the solution method between the lattice and super-cell calculations [4]. Though the results of the benchmark calculation based on the WIMS-AECL and SHETAN are in general acceptable, it is true that the uncertainty level is a little higher than that obtained by the standard design and analysis tools.

In this study, we have generated incremental cross-sections of the reactivity devices and structural material by the DRAGON code [5] for the Phase-B condition of the Wolsong-2 nuclear power plant (NPP). For the purpose of an inter-comparison among different solution models, the criticality was also calculated by the RFSP code based on the POWDERPUFS-V and MULTICELL codes.

2. Reactor and Analysis Models

The physics measurement data used for the benchmark calculation was obtained from the Phase-B test of the Wolsong-2 NPP performed in 1997. The Wolsong-2 NPP is a 713 MWe CANDU (CANDU-6) reactor and it is loaded with standard CANDU fuel bundles, which have 37 fuel rods. The core is loaded with two different fuel types: 0.72 wt% natural uranium fuel and 0.52 wt% depleted uranium fuel. The depleted uranium fuels are scattered in the inner core region [6].

The CANDU-6 reactor has 380 fuel channels and each fuel channel contains 12 fuel bundles. There are four major reactivity devices to control the excess reactivity and adjust the power distribution: liquid zone controller (ZCU), adjuster (ADJ), mechanical control absorber (MCA), and shutoff rod (SOR), which are symmetrically placed on the vertical mid-plane of the core.

The incremental cross-section is defined as a difference of the homogenized cross-sections of a 3-dimensional fuel lattice with and without a reactivity device. The input cross-sections of the 3-dimensional supercell, composed of the fuel, tubes, coolant, moderator, and the reactivity device, are provided by the WIMS-AECL cross-section library. In the core calculation by the RFSP code, the existence of a given reactivity device is represented by adding the incremental cross-sections to the homogenized cross-sections of a standard fuel lattice

The Phase-B test includes the first approach to a criticality and low power tests to verify the physics design and to evaluate the performance of the control and protective systems. In this study, the following cases were considered for the benchmark calculation:

- Approach to the first criticality,
- Calibration of the ZCU reactivity worth, and
- Estimation of the MCA and SOR worth.

3. Calculation Results

Table I shows the effective multiplication factor and critical boron concentration calculated by the DRAGON model, which are compared with the results based on the MULTICELL and SHETAN models. It can be seen that the effective multiplication factors are predicted with a good accuracy for the two DRAGON cases. The critical boron concentrations are also within an acceptance limit of 0.5 ppm. The reactivity worth of the ZCU was obtained by directly changing the ZCU water level, which is summarized in Table II. Compared to the measurement results for the typical operating range of 20%~60%, the maximum difference between the measurement and calculation is 4.6% for the DRAGON model with the ENDF/B-V library and 1.5-group energy structure, which is within the acceptance limit of 10%. If a 2-group energy structure with the ENDF/B-VI library is used, the relative error is reduced to 1.2%.

The relative error of the total reactivity worth is given in Table III for the MCA and SOR, which are strong absorbers. For the MCA, the prediction error of the total reactivity worth is 7.4% and 8.0% for the MULTICELL and SHETAN models, respectively. For the DRAGON code, the relative error of the total reactivity worth is distributed between 5% and 15%. If the 2-group energy structure is used with the ENDF/B-VI library, the maximum error is reduced to 6.6%. For the SOR, the

uncertainty level of the total reactivity worth prediction is similar to that of the MCA and is within the acceptance limit.

Table 1. Effective Multiplication Factors and Critical Boron Concentrations (CBC).

	MULTI-CELL	SHETAN (E-V)	DRAGON (E-V, 1.5G)	DRAGON (E-VI, 2G)
k_{eff}	0.99987	0.99648	0.99820	0.99812
CBC	8.98 ppm	8.55 ppm	8.76 ppm	8.76 ppm

*E-V: ENDF/B-V library, E-VI: ENDF/B-VI library
1.5G: 1.5-group energy structure, 2G: 2-group energy structure

Table II. Relative Error of the ZCU Level Worth.

ZCU level	MULTI-CELL	SHETAN	DRAGON (E-V, 1.5G)	DRAGON (E-VI, 2G)
20%～60%	0.1%	2.8%	4.6%	1.2%
20%～80%	-0.1%	2.5%	4.7%	1.1%

Table III. Relative Error of Total Reactivity Worth.

	MULTI-CELL	SHETAN	DRAGON (E-V, 1.5G)	DRAGON (E-VI, 2G)
MCA	7.4	8.0	14.9	6.6
SOR	6.4	10.5	13.6	5.2

4. Conclusion

The reactivity devices and structural material of the CANDU-6 reactor were modeled by the DRAGON code to obtain the incremental cross-sections to be used for a core analysis. Then the benchmark calculations were performed with different numbers of energy groups and cross-section libraries; and the results were compared with the physics measurement data of the Wolsong-2 NPP as well as the results obtained by the CANDU-6 reactor physics design tools. The results have shown that the DRAGON model predicts the criticality and reactivity device worth with a reasonable accuracy. The comparative study has also shown that the 2-group energy structure results in a better prediction especially for strong absorbers, while the effect of the cross-section library is not significant. Though the prediction error of the total reactivity worth is within the allowable uncertainty limit for all the reactivity devices, the estimation of an individual rod worth still has a relatively large error.

Acknowledgements

This work has been carried out under the Nuclear Research and Development program of the Korea Ministry of Science and Technology.

REFERENCES

[1] D.F. Torgerson, P.G. Boczar and A.R. Dastur, “CANDU Fuel Cycle Flexibility,” Bulletin of the Canadian Nuclear Society, 15, 24 (1994).
[2] P.G. Boczar, I.J. Hastings and A. Celli, “Recycling in CANDU of Uranium and/or Plutonium from Spent LWR Fuel,” AECL-10018, Atomic Energy of Canada Limited (1989).
[3] H. Choi, B.W. Rhee and H.S. Park, "Physics Study on Direct Use of Spent PWR Fuel in CANDU (DUPIC)", *Nucl. Sci. Eng*., **126**, 80 (1997).
[4] H. Choi, G. Roh, and D. Park, “Benchmarking MCNP and WIMS/RFSP Against Measurement Data – II: Wolsong Nuclear Power Plant 2,” *Nucl. Sci. Eng*., **150**, 37 (2005)
[5] G. Marleau, A. Herbert and R. Roy, “A User Guide for DRAGON,” IGE-174, Ecole Polytechnique de Montreal (1998).
[6] “Design Manual: CANDU 6 Generating station Physics Design Manual,” 86-03310-DM-000, Rev.1, Atomic Energy of Canada Limited (1995).