ASSESSMENT OF CANDU PHYSICS ANALYSIS TOOLS USING MEASUREMENT DATA OF WOLSONG NUCLEAR POWER PLANT 2

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ABSTRACT

Benchmark calculations have been performed for the CANDU physics analysis tools using the physics measurement data of the Wolsong-2 reactor. The benchmark calculations were performed for the criticality, boron worth, reactivity device worth, system temperature coefficient, and vertical/horizontal flux scan. The results have shown that the criticality is estimated within 3 mk, and the boron worth is underestimated by 0.55 mk/ppm. The calculated reactivity worths of control devices are in general consistent with the measurement results. However, the simulations have shown that the prediction error is especially large for individual strong absorber such as shutoff rod and mechanical control absorber.

1. INTRODUCTION

For Canadian deuterium uranium (CANDU) reactor analysis, a lattice code POWDERPUFS-V (PPV)[1] has been used. The application of PPV code is, however, limited to natural uranium fuel because of empirical correlations implemented. Therefore, a multigroup transport code WIMS-AECL[2] is widely used for the advanced CANDU fuel studies. The purpose of this study is to assess the performance of CANDU physics analysis method based on the lattice code WIMS-AECL using physics measurement (Phase-B) data of the Wolsong nuclear power plant 2.[3]

The commissioning program of a CANDU reactor is divided into several stages such as Phase-A, B, C, and D. The Phase-B test is conducted to verify and analyze the physics design of the CANDU reactor. For Wolsong nuclear power plant 2, the Phase-B physics test was performed in 1997.

2. PHYSICS ANALYSIS MODEL

For CANDU core analysis, three physics codes are typically used. In this study, the WIMS-

AECL and SHETAN[4] codes generate the fuel and reactivity device cross sections, respectively. The core simulation is performed by the current physics design code RFSP[5] to calculate the eigenvalue and flux distribution. The overall calculation scheme is shown in Figure 1.

The WIMS-AECL solves the cluster-type fuel geometry using the two-dimensional collision probability method (PIJ). The number of energy groups for the main transport calculation is 89, which is based on ENDF/B-V. For the leakage calculation, the B1 method with the Benoist diffusion coefficient was used.[6] The multi-group burnup-dependent cell-average cross sections generated by WIMS-AECL are collapsed into two-group lattice parameters by WIMTAB program.

The SHETAN is a three-dimensional collision probability code, which is used to model control devices and structural materials. In the core simulation, the presence of the reactivity device is represented by the incremental cross sections to the fuel cross section. The individual material cross sections used by the SHETAN is provided by the WIMS-AECL.

3. CORE SIMULATION

The Phase-B test includes the first approach to criticality and the low power tests necessary to verify the physics design and to evaluate the performance of control and protective systems. Most tests are performed at < 0.1% of full power.[7] The Phase-B tests are as follows;

a. Approaching to first criticality,
b. Calibration of liquid zone control unit (ZCU),
c. Reactivity calibration of devices – adjusters (ADJ), mechanical control absorbers (MCA), and shutoff rods (SOR),
d. Heat transport system temperature reactivity coefficient test,
e. Moderator temperature reactivity coefficient test, and
f. Flux distribution measurements.

3.1 Approach to First Criticality

At first, the criticality of the core was simulated. The critical operating conditions of the Phase-B measurement are as follows:

- The average zone level of zone controller is 16.94%.
- The purities of coolant and moderator are 99.63 and 99.84 wt%, respectively.
- The temperature of coolant and moderator is 35℃ and 29.5℃, respectively.
- The mechanical control absorber is inserted by 55% .
- The critical boron concentration is 9.0 ppm, and the error bound is ±0.5 ppm.

The simulation has shown that the eigenvalue of the initial core is 0.997, which is 3mk off the criticality.

3.2 Calibration of Liquid Zone Control Unit

The calibration of ZCU was performed at the initial condition without 55% insertion of the MCA. Since average zone level (AVZL) worth of the ZCU is calibrated by the boron concentration in the moderator, the boron reactivity coefficient was calculated at first. The boron reactivity coefficient is 7.75 mk/ppm boron. The calibration of the ZCU was performed by adding a boron batch whose worth is ~0.45 mk. Once a boron batch is added, the average ZCU water level is adjusted in order to maintain the criticality. The results are summarized in Table I, and the average ZCU worth is compared with the measured value in Table II for typical operating ranges.

3.3 Reactivity Calibration of Control Devices

The reactivity worth of individual ADJ was calculated. For 21 ADJs in the CANDU core, the maximum difference of the reactivity between calculation and measurement is ~21%. The root-mean-square (RMS) error of the worth calculation is 9.2%. The reactivity worths of ADJ banks were also calculated as shown in Table III. It can be seen that the device worths are consistently underestimated.

For MCA, the maximum and RMS errors of individual MCA worth estimation are 11.8 and 8.6%, respectively. The bank worth of MCA is given in Table IV, in which the total worth of MCA is over-estimated by 16.8%. For SOR, the maximum and RMS errors of individual rod worths are 25.5 and 12.4%, respectively. Unlike the case of ADJ worth calculation, the reactivity worths of MCA and SOR are overestimated by WIMS/RFSP.

3.4 Reactivity Coefficient Measurement

During the heat transport system temperature coefficient measurement, the moderator temperature was fixed to 35±1℃and the boron concentration in the moderator was 8.5 ppm. The coolant and fuel temperatures changed simultaneously from 35 to 260℃. The coolant density was calculated for D_2O at the saturated and non-boiling condition with 99.64 wt% purity. The reactivity change due to the variation of the heat transport system temperature is shown in Figure 2. The predicted heat transport system temperature coefficient is consistent with the measured data.

For the moderator temperature coefficient measurement, the coolant and fuel temperatures were fixed to 260±1℃ and the boron concentration in the moderator was set to 8.5 ppm. The moderator temperature coefficient was calculated by decreasing the moderator temperature from 69 to 35℃. The moderator density was calculated for D_2O at the saturated and non-boiling condition with 99.84 wt% purity. The variation of reactivity with the moderator temperature is shown in Figure 3. Compared with the measured data, the simulation underpredicts the reactivity variation by ～50%. It is thought that the error is largely dependent on the underpredicition of boron reactivity worth by WIMS/RFSP.

3.5 Vertical and Horizontal Flux Scan

During the Phase-B test, thermal flux scans have been performed several times for various operating conditions. The flux scan along a chord of the core is made with fission-chamber mapping detectors. The vertical fission-chamber scans are performed along 26 vertical flux detector (VFD) assemblies. The horizontal fission-chamber scan is carried out along the horizontal flux detector (HFD) tube. The flux scan simulations have been performed for the

following cases:
1: Nominal case,
2: MCA bank # 1 inserted by 50% with adjusters,
3: MCA all inserted with adjusters,
4: Without adjuster bank # 1, 2, 3, and 4, and
5: Without all adjusters.

During the simulation, the ZCU water level was fixed at 34.142% and the moderator boron concentration was 8.5 ppm. The flux calculations were performed by the INTREP module of RFSP code. The flux scans were obtained for the VFD #19 and HFD #1 for the vertical and horizontal fluxes, respectively. The horizontal and vertical normalized thermal flux distributions are shown in Figures 4 and 5, respectively. The RMS errors of flux calculations are summarized in Table V.

3.6 Discussion

For the criticality estimation, the difference of the critical boron concentration is ~0.5ppm. Considering the error requirement of the criticality (0.5 ppm), the simulation result is satisfactory. The calculated reactivity worths of ZCU, individual ADJ, and individual MCAs are generally consistent with measurement data within 15%. The maximum differences of MCA and ADJ bank worths in this case are 19% and 18%, respectively. For SOR, the worth is quite different from the measured value. Though the SORs are positioned symmetrically the rod worth are different from each other. For example, SOR #5, #8, #21, and #24 are located symmetrically, but the worths are 0.913, 0.979, 0.906, and 1.008 mk. In this case, the individual measured value is more or less unstable, but the total worth of SOR is generally consistent with measured value within 15%. For the flux scan, the vertical flux distribution is consistent with the measured one. However there was a minor measurement error during the horizontal flux scan, which can be seen in Table V and Figure 4.

CONCLUSION

The benchmark tests of the CANDU physics analysis tools have been performed using Wolsong-2 Phase-B measurement data. The estimation of the individual reactivity device worth by WIMS/RFSP has shown a consistent bias compared with the measurement results. Though the prediction error is relatively large, it is generally within the error requirement except for a few cases. In the future, it is recommended to evaluate the temperature data of the cross section library and to assess the incremental cross section generation procedure for reactivity devices.

ACKNOWLEDGEMENTS

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Table I. Comparison of Reactivity Worth for Average Zone Level

Boron Batch	Boron (ppm)	Reactivity (mk)	ZCU Level Change (%AVZL†)		Difference (%)‡
			Measurement	WIMS/RFSP	
1	0.058	0.449	10.10	9.56	-5.3
2	0.057	0.442	8.59	8.09	-5.8
3	0.058	0.451	7.18	7.43	3.5
4	0.058	0.449	6.54	6.98	6.7
5	0.058	0.449	6.64	6.45	-2.9
6	0.057	0.445	6.15	6.05	-1.6
7	0.058	0.447	6.14	5.90	-3.9
8	0.058	0.449	5.98	5.86	-2.0
9	0.058	0.453	5.96	6.00	0.7
10	0.057	0.445	6.37	6.00	-5.8
11	0.057	0.444	6.12	5.63	-8.0
Total	0.635	4.924	77.87	73.95	-5.0

† AVZL : Average zone level

‡ Difference = (WIMS/RFSP-Measurement)/ Measurement *100

Table II. Comparison of Average Zone Level Worth

AVZL(%)	AVZL Worth (mk/%)		Difference(%)
	Measurement	WIMS/RFSP	
20 ~ 60	0.07166	0.07368	2.8
20 ~ 80	0.06769	0.06938	2.5

Table III. Reactivity Worth of Adjuster Banks

Bank Number	Bank Worth (mk)		Difference (%)
	Measurement	WIMS/RFSP	
1	1.36	1.236	-9.1
2	1.53	1.399	-8.6
3	1.51	1.387	-8.1
4	2.33	2.021	-13.3
5	1.77	1.5	-15.3
6	1.79	1.524	-14.9
7	3.37	2.703	-19.8
Total	13.66	11.77	-13.8

Table IV. Reactivity Worth of Mechanical Control Absorber Banks

Bank Number	Bank Worth (mk)		Difference (%)
	Measurement	WIMS/RFSP	
1 (MCA #1 & 4)	4.85	5.60	15.4
2 (MCA #2 & 3)	4.73	5.60	18.4
Total	9.58	11.20	16.9

Table V. RMS Error (%) of Horizontal and Vertical Flux

		CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
Horizontal	RMS Error(%)†	11.76	10.04	20.65	11.60	8.60
Vertical	RMS Error(%)	12.85	4.02	4.23	4.06	1.66

†RMS Error (%) : root-mean-square

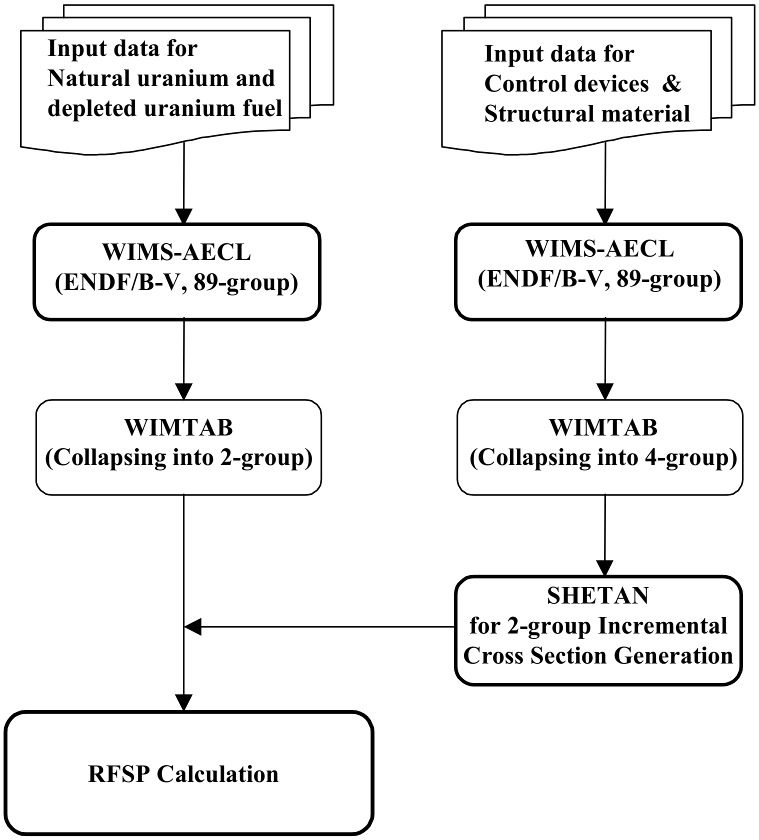

Figure 1. Physics Calculation Scheme

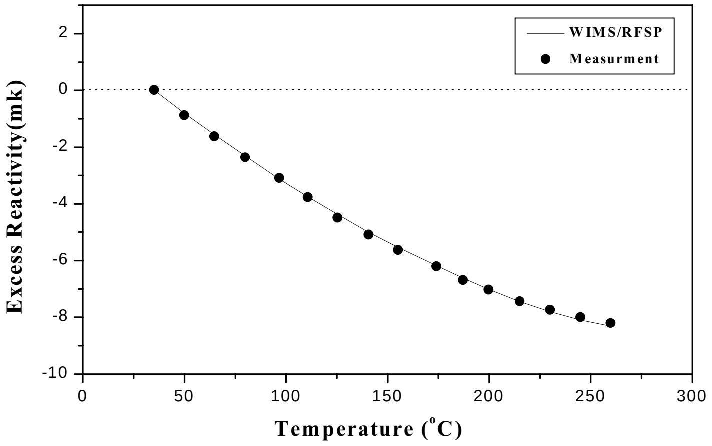

Figure 2. Heat Transport System Temperature Effect

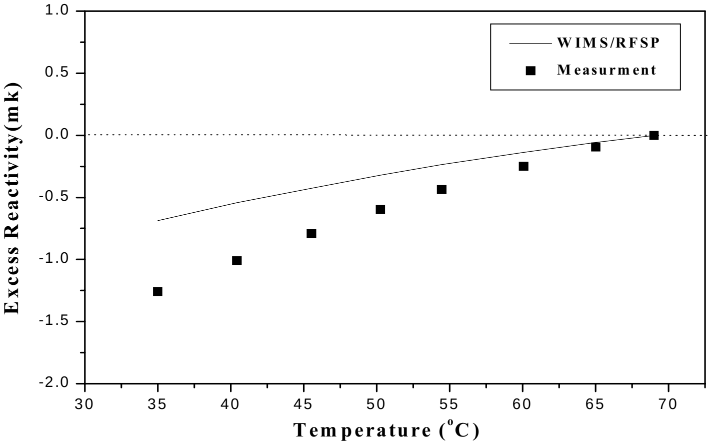

Figure 3. Moderator Temperature Effect

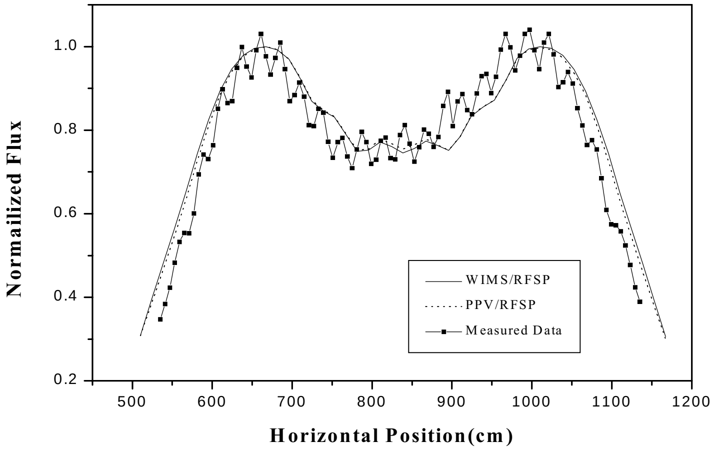

Figure 4. Horizontal Flux Scan for Case 1

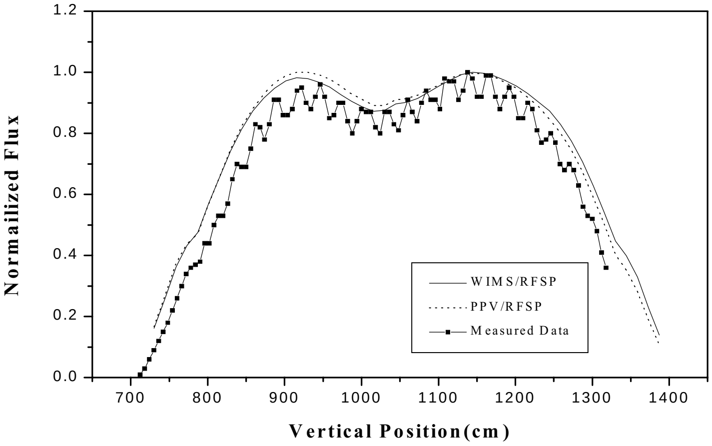

Figure 5. Vertical Flux Scan for Case 1