Benchmark Calculations of Phase-B Test about CANDU

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1. Introduction

The physics parameters were measured during the Phase-B commissioning period, which included the first approach to criticality and the low power tests necessary to verify the physics design and to evaluate the performance of the control and protective systems.

Benchmark calculations of CANDU (Canada deuterium uranium) reactor physics design and analysis codes have been performed by using a lattice code WIMS-AECL[1] , a supercell code DRAGON[2] and a core analysis code RFSP (Reactor Fuelling Simulation Program)[3] for the physics measurement data of Wolsong unit 2 nuclear power plant. The lattice and reactivity device models were examined based on Wolsong unit 2 measurement data for the criticality and reactivity device worth. The standard CANDU fuel lattice and the reactivity device models of a CANDU reactor were sufficiently investigated to set up the reference lattice and reactivity device models based on the Wolsong Unit 2 measurement data. Compared to a measurement data, this study shows that the results of the criticality and reactivity device worth calculations.

2. Calculation Model and Method

The lattice parameters are generated by WIMS-AECL, which is a multigroup transport code for the fuel lattice and depletion calculations. The collision probability method was chosen to model the two-dimensional geometry with a 33-group cross-section library. And a simplified lattice-depletion code SCM[1] has been developed as a surrogate of WIMS-AECL in RFSP to perform the lattice calculation for each bundle at each time step, so as to treat local parameters and their history for each bundle individually. The SCM code is an one-dimensional multigroup diffusion code and the three homogenous regions are the fuel-clad-coolant, tube and moderator region.

The incremental cross sections were found the difference between homogenized cross sections of a three-dimensional fuel lattice with and without a reactivity device, which can be obtained by the DRAGON code. DRAGON solves the multigroup neutron transport equation for general geometries and use microscopic cross-section libraries with the WIMS format.

The CANDU reactor contains 4 types of major reactivity devices such as adjusters (ADJ), shutoff rods (SOR), mechanical control absorbers (MCA), and liquid zone controller systems (LZCs). These devices are supported by structural materials in the reactor core. Reactivity devices and structural materials are represented by incremental cross sections in the reactor analysis by the RFSP code.

The core calculation is performed by RFSP, which is a three-dimensional diffusion code. In the RFSP code, the finite difference model is used to divide the reactor core, including the reflector region, into rectangular parallelepipeds.

3. Calculation of Phase-B Post Simulation

3.1 Phase-B condition for Wolsong Unit 2

The Phase-B test is a part of the overall commissioning program of CANDU reactors and conducted to confirm and analyze the physics parameters of the CANDU reactor. Most of the physics measurement of physics parameters are fulfilled under a zero power operation condition.

For Phase-B condition, the CANDU core was loaded with two different fuel types: 0.72 wt% natural uranium fuel and 0.52 wt% depleted uranium fuel. Four major reactivity devices were installed to control the excess reactivity and adjust the power distribution.

3.2 Approach to the First Criticality

Critical boron concentration is about 8.5 ppm for Wolsong unit 2.[4] The errors of the critical boron concentration between measurement and calculation was 5.5%, which was within the uncertainty level of the critical boron concentration measurement.

3.3 Calculation of Liquid Zone Control System

During the Phase B test, the LZCs was calibrated by dissolving a boron batch in the moderator. After one boron batch was added, the average LZCs water level was automatically adjusted in order to maintain a criticality. The reactivity worth of the LZCs was then calculated for the initial core condition. Because the LZCs was calibrated by a boron concentration change in the moderator, the boron reactivity coefficient was calculated first. The boron reactivity coefficient was 8.2354 mk/ppm for Wolsong unit 2, for the boron concentration of 9 to 10 ppm. The calculated AVZL worth is given in table 1 and compared with the measurement results.

Table 1. Calibration of the LZC worth (mk/%)

	Measured	WIMS/RFSP	Error(%)
AVZL 20~60(%)	0.07139	0.07253	1.57
AVZL 20~80(%)	0.06702	0.06827	1.83

The prediction error of the LZCs worth is less than 2% for the Wolsong unit 2.

3.4 Calibration of Reactivity Devices

Table 2 showed the total worth of reactivity devices. The reactivity worth of the individual reactivity device was calculated by removing one at a time with all others inserted. The error of the total ADJ worth between the calculation and measurement is -1.02%. And the error of the total MCA worth is 8.07%. Also the error of the total SOR worth is 6.4%.

Table 2. Reactivity worth of devices

	Measured	WIMS/RFSP	Error(%)
ADJ total	10.881	10.770	-1.02
MCA total	7.713	8.336	8.07
SOR total	45.378	48.632	6.4

3.5 Reactivity Coefficient Test

The temperature change effect of the heat transport system (HTS) and moderator was measured. For HTS temperature coefficient measurement, the moderator temperature was fixed at 35˚C. The coolant and fuel temperatures were the same, and they were varied from 35˚C to 260˚C. The coolant density was calculated for D_2O at saturated and nonboiling conditions. The variation of the HTS temperature coefficient is shown in figure 1 (left). The HTS temperature coefficient is generally consistent with the measured data within a maximum error of ~14%.

For the moderator temperature coefficient (MTC), the coolant and fuel temperatures were fixed at 260˚C. The MTC was calculated by decreasing the temperature from 69˚C to 35˚C. The moderator density was calculated for D_2O at saturated and nonboiling conditions for the Wolsong unit 2. The variation of the MTC is shown in figure 1 (right). Compared with the measured data, the simulation error was relatively 3.5%. .

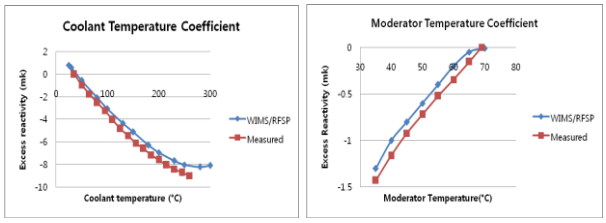

Figure 1. Coolant temperature coefficient (Left) and moderator temperature coefficient(Right)

4. Conclusion

Benchmark calculations were performed for the Phase-B tests of the Wolsong Unit 2. The benchmark calculations were performed for the critical boron concentration, LZCs reactivity worth, reactivity device worth, temperature coefficient of which the allowed uncertainties are ±0.5 ppm, ±10%, ± 15% and ±25 %, respectively. This study shows the CANDU physics design and analysis codes have predicted the physics parameters within the allowed uncertainty level.

REFERENCES

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