VALIDATION OF MCNP-4B CODE AGAINST MEASUREMENT DATA OF WOLSONG NUCLEAR POWER PLANT 2

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ABSTRACT

The benchmark calculations have been performed for MCNP-4B code using the measurement data of Wolsong nuclear power plant 2. In this study, the benchmark calculations have been done for the criticality, boron worth, reactivity device worth, reactivity coefficient, and flux scan. Cross-section libraries were newly generated from ENDF/B-VI release 3 through the NJOY97.114 data processing system and a three-dimensional full core model was developed for MCNP calculation. The simulation results have shown that the criticality is estimated within 4 mk and the estimated reactivity worth of the control devices are generally consistent with the measurement data. In certain cases, the simulation results have shown large discrepancies against the measurement data, which will be studied further in the near future.

1. INTRODUCTION

The MCNP-4B code[1] was assessed against the measurement data[2] of Wolsong nuclear power plant 2, which was obtained from Phase-B test performed in 1997. The Phase-B test is a part of the overall commissioning program of a CANDU reactor and conducted to verify and analyze the physics design of the CANDU reactor. In this study, these measurement data are used to validate the MCNP-4B simulation model. After benchmarking MCNP code against available experiment data, it will be used in the future as the reference tool to validate design and analysis codes for the advanced CANDU fuels of which the experimental data are not available.

In this study, a three-dimensional full core model was developed using MCNP code and the benchmark calculations have been performed for the criticality, boron worth, reactivity device worth and flux scan. The MCNP cross-section libraries were newly generated from ENDF/B-VI release 3 [Ref. 3] through NJOY97.114 data processing system.[4]

2. DEVELOPMENT OF A MCNP MODEL

Phase-B includes the first approach to criticality and 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.[5] The Phase-B test items are as follow;

- approach to first criticality,
- calibration of liquid zone controller unit (ZCU),
- reactivity calibration of devices - adjusters (ADJ), mechanical control absorbers (MCA), and shutoff rods (SOR),
- heat transport system temperature reactivity coefficient test,
- moderator temperature reactivity coefficient test, and
- flux distribution measurements.

Though the computing time is tremendous, a three-dimensional full core model including reactivity devices was developed for the MCNP calculation, for eliminating the modeling uncertainties associated with the homogenization process which is typically adopted in the design code system. In order to facilitate the explicit modeling of fuel bundles in the core, a repeated structure option of MCNP was used. This option makes it possible to describe a cell and surfaces only once to model their distribution in a core, and therefore, a total of 4560 bundles in a CANDU core was fully modeled including the fuel pellet, cladding, pressure tube and calandria tube except for the fuel gap, end cap and end plate. All reactivity devices were explicitly modeled except for the structural material such as tension spring, locator, bracket, etc. The end shield materials were simplified by concentric annuli at each end of the fuel channel.

Because the public MCNP cross-section libraries have a limited number of isotopes and temperature data, it is not sufficient to analyze various fuels which have complex isotopic compositions. Therefore, in order to use the cross section data consistently for the fuels to be analyzed in the future, new cross-section libraries were generated based on ENDF/B-VI release 3. In this study, the NJOY nuclear data processing system version 97.114 was used and the library generation was performed on HP9000 C180EG workstation under HP-UX 10.20 operating system. The fractional tolerance used in NJOY input parameter is 0.1%. The neutron $S(\alpha, \beta)$

thermal cross-section data were used for the light water and heavy water medium to take account of the thermal motion of the target molecules and were also newly generated. All MCNP calculations were performed with 50,000 particles per cycle and 2,000 active cycles after 100 inactive cycles.

3. BENCHMARK CALCULATION OF A CANDU CORE

3.1 Criticality Calculation

At first, criticality of the core was simulated. The critical operating conditions of the critical core are as follow;

· average zone level of ZCU is 16.94%,
· purities of coolant and moderator are 99.63 and 99.84 wt%, respectively,
· temperature of coolant and moderator is 34.96℃ and 29.50℃, respectively,
· MCA #4 is inserted by 55%, and
· critical boron concentration is 9.0 ppm and error bound is ±0.5 mk.

The calculated effective multiplication factor of the critical operating condition is 0.99649± 0.00005, and the discrepancy from the criticality is 3.51 mk. When MCNP-4B simulation approaches to the criticality, the boron concentration is ~8.55 ppm. Therefore, the discrepancy of the critical boron concentration is 0.45 ppm, which is within the error bound (~0.5 ppm).

3.2 Reactivity Device Worth

Reactivity Worth of ZCU

During the Phase-B test, the calibration of the ZCU is performed by dissolving the boron batch in the moderator, which corresponds to the reactivity worth of ~0.45mk. After the boron batch is added, the average ZCU water level is adjusted to maintain core criticality. On other hand, the ZCU was obtained by directly changing the ZCU water level in the MCNP simulation. Then, the calculated average ZCU worth was compared with the measurement result as given in Table 1 for the typical operating range. The maximum error between the measurement and calculation is 1.66%. However, this is integral effect which summed of over- and under-predicted worth of each boron batches. For each boron batches, the maximum error between the measurement and calculation is ~10%.

Reactivity Worth of ADJ

Because the reactivity of individual ADJ is so small, it is not appropriate to simulate individual ADJ by MCNP. Therefore the reactivity worth of ADJ banks was calculated by MCNP, which is more close to the actual operating procedure of ADJ system in the CANDU reactor. The results are summarized in Table 2, in which the maximum difference of the ADJ bank worth is ~22%. For all cases, the ADJ bank worth are consistently under-estimated.

Reactivity Worth of MCA

The calculated reactivity worth of individual MCA and MCA banks is given in Tables 3 and 4, respectively. The results are consistent with measurement data within 15% and the maximum differences are 8% and 1% for individual MCA and MCA bank, respectively. Like the case of ADJ reactivity calculation, the reactivity worth of MCA are generally under-predicted by MCNP.

Reactivity Worth of SOR

The calculated reactivity worth of individual SOR is given in Table 5 for selected several SOR rods which shown relatively large differences between calculated and measured data. The results are generally consistent with measurement data within 15% and the maximum difference is 20%. The reactivity worth of SOR is also under-predicted by MCNP.

Flux Distribution

In order to confirm the physics design of the core and to check the effects of the various reactivity devices, thermal flux scans are performed for various reactor configurations. Flux scans along a cord of the reactor core are made with the fission chamber in vertical and horizontal directions. In case of Phase-B test of Wolsong nuclear power plant 2, the vertical and horizontal fluxes are measured in the vertical flux detector (VFD) #19 and horizontal flux detector (HFD) #1, respectively.

The flux distribution was calculated using cell detector tally (F4) of MCNP. The cell detector is a sphere of the radius of 0.938 cm, which is located in the VFD #19 and HFD #1 guide tube. During the simulation, the average ZCU level was fixed at 40.0%, and the moderator boron concentration was 9.0 ppm. In order to reduce the error for the level of ±5%, the MCNP calculation was performed with 100,000 particles per cycle and 2,000 active cycles after 100 inactive cycles.

For the nominal case, the normalized vertical and horizontal flux distributions are shown in Figs. 1 and 2, respectively. The root mean square errors of the vertical and horizontal flux calculations are 5.96% and 6.34%, respectively.

4. CONCLUSION

Benchmark calculations of the MCNP code have been performed using Wolsong-2 Phase-B measurement data including a three-dimensional full core model development of a CANDU reactor. The results obtained in this study are generally consistent with the measurement data except for a few parameters which have relatively large errors at the moment. Therefore, the sensitivity calculations are required to know the reason of the discrepancies for the similar cases. In near future, Wolsong-3 and 4 Phase-B measurement data will be verified using MCMP code, and then it will be used in the future as the reference tool to validate design and analysis codes for the advanced CANDU fuels of which the experimental data are not available.

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TABLE 1. COMPARISON OF AVERAGE ZONE LEVEL WORTH

	MCNP-4B	Measurement	Difference (%)
AVZL 20～60% (mk/% AVZL)	0.070474	0.071665	1.66
AVZL 20～80% (mk/% AVZL)	0.066842	0.067691	1.25

TABLE 2. REACTIVITY WORTH OF ADJUSTER BANK

Bank No.	ADJ Rod No.	MCNP-4B	Measurement	Difference (%)
1	1,7,11,15,21	1.159±0.071	1.36	-14.81
2	2,6,18	1.454±0.070	1.53	-4.94
3	4,16,20	1.460±0.070	1.51	-3.30
4	8,9,13,14	2.088±0.070	2.33	-10.37
5	3,19	1.400±0.070	1.77	-20.88
6	5,17	1.701±0.070	1.79	-4.98
7	10,12	2.575±0.069	3.37	-23.60

TABLE 3. REACTIVITY WORTH OF
INDIVIDUAL MECHANICAL CONTROL ABSORBER

MCA Rod No.	MCNP-4B	Measurement	Difference (%)
1	1.783±0.071	1.885	-5.42
2	1.793±0.071	1.944	-7.78
3	1.823±0.071	1.876	-2.83
4	1.913±0.071	2.009	-4.76

TABLE 4. REACTIVITY WORTH OF MECHANICAL CONTROL ABSORBER BANK

MCA Bank	MCA Rod No.	MCNP-4B	Measurement	Difference (%)
1	1,4	4.812±0.071	4.850	-0.78
2	2,3	4.752±0.071	4.730	0.46

TABLE 5. REACTIVITY WORTH OF INDIVIDUAL SHUTOFF RODS

SOR Rod No.	MCNP-4B	Measurement	Difference (%)
1	1.141±0.071	1.292	-11.71
3	1.412±0.071	1.598	-11.68
4	1.101±0.071	1.310	-15.98
9	1.161±0.071	1.313	-11.56
13	1.131±0.071	1.395	-18.94
15	1.221±0.071	1.421	-14.08
16	1.251±0.071	1.573	-20.44
19	2.054±0.071	2.334	-11.99
20	1.111±0.071	1.382	-19.63
26	1.412±0.071	1.593	-11.36
28	1.171±0.071	1.351	-13.34

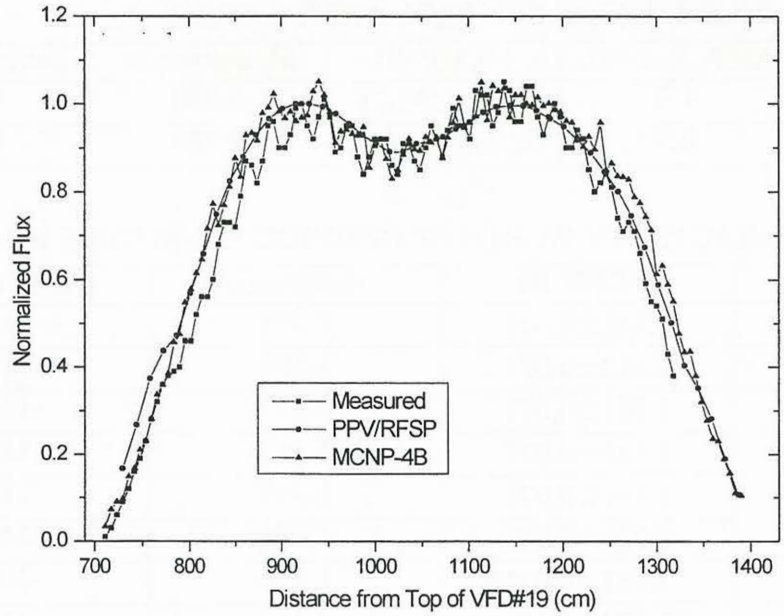

FIG. 1. VERTICAL FLUX SCAN FOR NOMINAL CASE

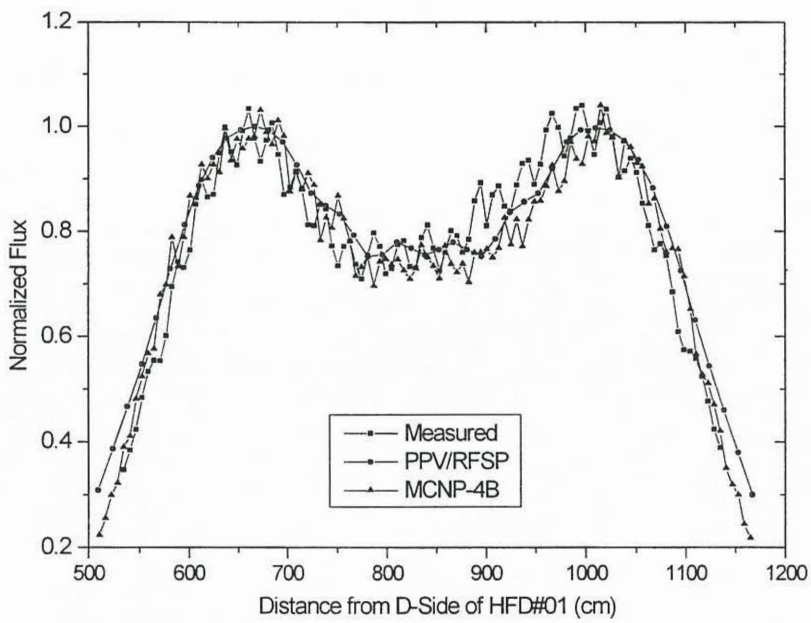

FIG. 2. HORIZONTAL FLUX SCAN FOR NOMINAL CASE