Comparison Of Bundle Powers In An LVRF Core Using RFSP And MCNP

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ABSTRACT

This study determined whether replacing Natural Uranium fuel (NU) with Low Void Reactivity Fuel (LVRF) in two fuel channels at a Bruce B unit induces any additional uncertainties upon bundle powers calculated by the compliance code Simulation of Reactor Operation (SORO). The Monte Carlo N-Particle Transport Code (MCNP) was used as a surrogate for experimentation, while the Reactor Fuelling Simulation Program (RFSP) was used as a surrogate for SORO. The mean difference between bundle powers calculated by the two codes (~1%) was determined to be similar to the MCNP modelling uncertainty. Thus, no additional penalty was required for the use of SORO due to the presence of 2 LVRF channels within an NU core.

INTRODUCTION

Bruce Power is planning to use LVRF in two fuel channels at a Bruce B unit in place of NU fuel in a demonstration irradiation (DI) of the new fuel. Since there are two channels, nominally L2 and O8, in which progressive fuelling with LVRF bundles is planned, the core will contain a more heterogeneous fuel configuration than for an all NU core. There is a need to determine whether this heterogeneity induces any additional uncertainties in the calculation of bundle powers by SORO. As there was no direct experimental evidence on which to establish the modeling uncertainty, the computer code MCNP Version 4C[1] was used as a surrogate for experimentation. Furthermore, RFSP-IST (Version DEV_3-01-00P04)[2] was used as a surrogate for the compliance code SORO upon the request of the client, as the two have very similar neutronics-analysis methodologies (2-energy-group, finite-difference homogenized-cell diffusion theory) and previous work beyond the scope of the current study has shown that they yield similar results with equivalent assumptions. This substitution, followed by comparison of calculated bundle powers with MCNP, also served to validate the use of RFSP in cases of reactor fuelling simulation with LVRF.

METHODOLOGY

Using the material and geometric configurations of the fuels provided by AECL and Bruce Power, two natural uranium channels (L2 and O8) were changed into LVRF channels in the RFSP and MCNP core models. The TAVEQUIV (time-average equivalent) module in NSS' existing RFSP model for a Bruce B core was used to generate a snapshot of the irradiation distributions in the fuelled reactor. The Winfrith Improved Multigroup Scheme program (WIMS-AECL Release 2.5d)[3] was used to generate the fuel compositions necessary for MCNP calculations. The WIMS input files were also provided by AECL. However, the pseudo fission product concentrations calculated by WIMS were not used in MCNP due to input file limitations (WIMS uses 2 pseudo fission product nuclides to represent the residual reactivity of minor fission-product nuclides; the impact on the core reactivity was estimated to be on the order of 1 mk). Channel and bundle powers for the DI channels were determined from the fission tallies calculated by MCNP. Six MCNP models were created, as outlined in Table 1.

TABLE 1: LISTING OF MATERIAL PROPERTIES IN DI CHANNELS

Case Name	Coolant		Fuel Temp (K)	Moderator Temp (K)	D_2O molecular %	
	Temp (K)	*ρ (g/cm^3)*			*Coolant*	*Moderator*
12 LVRF*	557.16	0.82048	900	341.36	98.882	99.9453
8 LVRF	557.16	0.82048	900	341.36	98.882	99.9453
4 LVRF	557.16	0.82048	900	341.36	98.882	99.9453
Reduced fuel temperature	557.16	0.82048	800	341.36	98.882	99.9453
Reduced coolant temperature	457.16	0.97872	900	341.36	98.882	99.9453
NU only	557.16	0.82048	900	341.36	98.882	99.9453

*12 LVRF refers to the case where 12 LVRF bundles were present in both channels L2 and O8.

The RFSP bundle powers in the DI channels were provided by AECL. The development of the RFSP models used to calculate these bundle powers was, however, beyond the scope of this study.

THE FOLLOWING MODELING ASSUMPTIONS WERE MADE IN THIS ANALYSIS:

1. The LVRF and NU fuel composition and dimensions were the same as those specified by Bruce Power.
2. Fuelling was performed in both DI channels simultaneously and the number of LVRF bundles replacing NU bundles was always identical. The first case modelled contained 4 LVRF bundles in L2 and O8 each, while the next two contained 8 and 12 LVRF bundles, respectively. Fuelling was in the flow direction in both DI channels (see Table 1 for a description of the different cases modelled).
3. There were no reactivity devices or structural materials present in the core in any of the MCNP and RFSP models. As any errors associated with these devices and materials are already accounted for in the present compliance methodology, they were excluded from this comparison. Furthermore, this exclusion kept the effort of producing the corresponding MCNP simulations at a manageable level.
4. The material properties of the fuel and coolant in the various cases are summarized in Table 1. Moderator conditions were not varied in these analyses and were kept at the typical Bruce B purity and temperature.
5. The LVRF and NU fuel temperatures were the same in the reduced fuel temperature case. Both reduced temperature models were created by changing the fuel temperature and coolant temperature in the 12 LVRF bundle model.
6. In the reduced coolant temperature case, the same coolant was placed in contact with both fuels.
7. Since the fission tallies calculated by MCNP were in units of *MeV/source neutron*, a suitable conversion factor into conventional units like *Watts* was required. Accordingly, the weight loss due to fission for each nuclide represented in the problem was extracted from the MCNP output. The weight losses for 4 significant fissile nuclides (U-235, U-238, Pu-239, and Pu-241) were multiplied by the energy/fission for each nuclide, and then summed. By taking the ratio of this calculated energy value with the total fission power in the core (2,703 *MW* as inputted into RFSP), the conversion factor was found to be approximately 3.38×10^{7} *W.source neutron/MeV*.

RESULTS AND DISCUSSION

For the purpose of the following discussion, bundle locations are numbered from 1 to 12 beginning from the fuelling end of each channel. A summary of the results is presented in Table 2.

TABLE 2: SUMMARY OF MAJOR FINDINGS

PARAMETER	VALUE
Fraction of bundle locations where bundle power difference* < 5%	90%
Maximum bundle power difference	13.6%
Average bundle power difference	0.94%
Average bundle power uncertainty	1.60%

* bundle power difference = $(Power_{MCNP} - Power_{RFSP})/Power_{RFSP}$

For the 2 DI channels, the difference between the MCNP calculated and RFSP calculated bundle powers was generally less than 5%. While there were relatively large differences in bundle powers (up to 13.6%) at the ends of the channels, they were not considered important as it was expected that the diffusion approximation and the transport solution would differ more at the core periphery than at its center. As well, the powers in the bundles in positions 1 and 12 were significantly lower than the more relevant ones in the central portion of the core. Thus, the magnitude of any individual difference was small, as shown in Tables 3 and 4. As a result, these differences will not affect the compliance results.

TABLE 3: COMPARISON OF BUNDLE POWER DIFFERENCES BETWEEN RFSP AND MCNP BUNDLE POWERS ACROSS LVRF CASES

BUNDLE LOCATION	AVERAGE DIFFERENCE (*MCNP – RFSP*) [kW]	AVERAGE UNCERTAINTY [kW]	AVERAGE MCNP BUNDLE POWER [kW]
Edge Bundles			
O8/BUNDLE 1	11.7	7	304
O8/BUNDLE 12	3.4	2	43
Central Bundles			
O8/BUNDLE 6	4.3	13	1,079
O8/BUNDLE 7	13.1	12	1,038

TABLE 4: COMPARISON OF BUNDLE POWER DIFFERENCES BETWEEN RFSP AND MCNP BUNDLE POWERS IN NU-ONLY CASE

BUNDLE LOCATION	DIFFERENCE (*MCNP – RFSP*) [kW]	UNCERTAINTY [kW]	MCNP BUNDLE POWER [kW]
Edge Bundles			
O8/BUNDLE 1	0.3	6	265
O8/BUNDLE 12	2.8	2	43
Central Bundles			
O8/BUNDLE 6	20.3	12	1,079
O8/BUNDLE 7	23.9	12	1,038

The mean difference between the MCNP and RFSP bundle powers (including the edge bundles) over the five LVRF cases modeled was found to be 0.94%, which was similar to the 1.6% average uncertainty of the MCNP results (based on a mean uncertainty of 7.9 kW against an average bundle power of 489 kW over 120 bundles, i.e., 12 bundles each in O8 and L2 per case, times 5 cases). Therefore, the tables show that there was little difference between the RFSP and MCNP calculated bundle powers.

In the central bundles, the greatest bundle-power differences appeared for the case of 8 LVRF bundles in channel O8. For this case, the maximum observed difference was 4.1% at bundle location 7. Even here, the difference was comparable to the difference observed for the NU case (2.3%) at this location when combined with the uncertainties present in both calculations. Specifically, the differences in bundle power were calculated to be 42 ± 12.1 kW and 24 ± 12.6 kW, for the LVRF and NU bundles, respectively.

Finally, in the high power channel O8, the absolute difference in all bundle positions was of the same order as the MCNP uncertainty. In only 4 of the 72 bundles over the 6 models (i.e., 12 bundles in O8 per model, times 6 models) was the bundle power difference greater than three times the MCNP uncertainty.

CONCLUSIONS

It can be concluded based on the preceding discussion that MCNP and RFSP calculated similar bundle powers for the channels studied, and there appear to be no additional uncertainties associated with the simulation of two LVRF channels in a Bruce B core with RFSP. Since RFSP has earlier been shown to be an acceptable surrogate for SORO for this work, it can be concluded that there is no additional penalty required during the use of the compliance code SORO in the DI case.

REFERENCES

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