Research Article

Calculations for a BWR Lattice with Adjacent Gadolinium Pins Using the Monte Carlo Cell Code Serpent v.1.1.7

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Monte Carlo neutron transport codes are usually used to perform criticality calculations and to solve shielding problems due to their capability to model complex systems without major approximations. However, these codes demand high computational resources. The improvement in computer capabilities leads to several new applications of Monte Carlo neutron transport codes. An interesting one is to use this method to perform cell-level fuel assembly calculations in order to obtain few group constants to be used on core calculations. In the present work the VTT recently developed *Serpent v.1.1.7* cell-oriented neutronic calculation code is used to perform cell calculations of a theoretical BWR lattice benchmark with burnable poisons, and the main results are compared to reported ones and with calculations performed with *Condor v.2.61*, the INVAP's neutronic collision probability cell code.

1. Introduction

The Monte Carlo method is traditionally used in neutronic calculations to solve criticality and shielding problems due to its capability to model complicated geometries and its quasicontinuous energy treatment. However its high computational requirements had restricted its applications to other areas in neutronic calculations. With the advance in computer performance the use of this method to perform cell calculations to obtain few group constants arises as a very promising future application. This application is even more interesting when few group constants are needed to core calculations involving high heterogeneous 3D devices, such as irradiations facilities.

The *Serpent* code [1] is a new Monte Carlo continuous-energy neutron transport code developed in the VTT Technical Research Centre of Finland oriented to pin cell calculations with the capability of burnup and few group constants generation. Nowadays this code is oriented to pintype assembly calculations, but it has the capability to model more general 3D geometries, which makes it an interesting option to obtain few group constants in complicated devices on a reactor core.

In the present work a well-known BWR lattice benchmark calculation [2] is performed using *Serpent* code and nuclear data from ENDF/B-VI.8. The main results are compared with reported values and with calculations performed with the INVAP's collision probability code *Condor* [3] using nuclear data from WIMS library (69 groups) [4] and WLUP library (172 groups) [5].

2. Models

The fuel element with adjacent poisoned pins with Gadolinium reported on the theoretical benchmark [2] was modeled in *Serpent* and *Condor* codes. This fuel element consists of a 4×4 pin assembly with two Gadolinium poisoned pins. The main characteristics are listed on Table 1.

The models developed in *Condor* (using Collision probabilities 2D) and *Serpent* (using Monte Carlo 2D) are shown on Figures 1(a) and 1(b), respectively.

As it can be seen, the Gd pins were divided into four zones in both models. In addition all the pins were divided in four zones on *Serpent* model. Regarding burnup calculations, the *Condor* model evolves each zone individually, while the developed *Serpent* model only differs in the evolution for

FIGURE 1: Models developed for BWR cluster (a) *Condor v 2.61* (b) *Serpent v. 1.1.7*.

FIGURE 2: Burnup results for both models.

the two types of fuel pin. The Condor model was run using nuclear data from esin2001 [4] library (based on WIMS-69) and WLUP library [5] (172 groups). Serpent model was run using nuclear data from ENDF/B-VI.8 in ACE format. Both Condor and Serpent burnup calculations used the predictor-corrector method. Condor burnup calculations evolved the isotopes included on the burnup chain defined on each library used. In Serpent code the decay and fission data is obtained directly from the ENDF/B-VI.8 library, but inventory report was demanded for 70 isotopes.

3. Results Comparison

Results were obtained for both models. The running time (sequential, notparallel mode) involved on Serpent calculations reached 435 min on a 2 Ghz CPU, while the calculations performed on Condor code required 4 minutes for esin2001 library and 10 min for EWLUP 172 for the same CPU.

Results regarding infinite multiplication factors, main isotope evolution, and flux profiles were compared. Table 2

TABLE 1: Problem specification.

Fuel	
Material	UO ₂
Density	10 g/cm ³
Temperature	600° C
U-235 enrichment	3% wt
Diameter	1 cm
Gd-pin poison	Gd ₂ O ₃
Poison percentage on Gd-Pin	3% wt
Average power density	20 W/g
Clad	
Material	Zircaloy-2
Density	6.55 g/cm ³
Temperature	300° C
Inner diameter	1 cm
Outer diameter	1.2 cm
Moderator	
Material	H ₂ O
Void	0%
Condition	Saturated at 286° C and 70.06 bar
Lattice pitch	1.6 cm

shows the results for the infinite multiplication factor for fresh/hot/clean condition. Serpent result includes the statistical convergence.

In addition, results for burnup evolution for both models and those reported on the benchmark are shown on Figure 2.

As it can be seen from Table 2 and Figure 2 a good agreement exist between both codes and benchmark results. Furthermore, reactivity results obtained with Serpent have a better agreement with those obtained with *Condor + EWLUP 172* due to the fact that nuclear data sets are similar.

Another comparison regarding isotope burnup was performed. The evolution for ²³⁵U, ²³⁹Pu, and ¹⁵⁵Gd in the poisoned pin are shown on Figures 3, 4, and 5, respectively.

TABLE 2: Results for Clean/Hot/Fresh condition.

	Serpent	Condor + esin2001	Condor + EWLUP 172	Benchmark
k infinite	1.0016 $\pm$ 0.0007	0.9908	1.0062	1.0014 $\pm$ 0.011

TABLE 3: ^{155}Gd Radial distribution at 2000 MWd/tonU in the poisoned pin.

Mean radius (cm)	Benchmark	Benchmark Stdev	^{155}Gd numerical density [at/cmb]		
			<i>Serpent</i>	<i>Condor</i> + esin2001	<i>Condor</i> + EWLUP 172
0.125	1.29E-04	3.4E-06	1.28E-04	1.28E-04	1.29E-04
0.302	1.20E-04	3.3E-06	1.18E-04	1.18E-04	1.19E-04
0.393	9.41E-05	3.8E-06	9.25E-05	9.00E-05	9.31E-05
0.467	4.95E-05	8.6E-06	4.71E-05	4.26E-05	4.60E-05

FIGURE 3: ^{235}U burnup in the poisoned pin. FIGURE 5: ^{155}Gd burnup in the poisoned pin. FIGURE 4: ^{239}Pu in the poisoned pin. FIGURE 6: Thermal flux profiles on both models for two different vertical positions ($x, y = 0, 0$ is the centre of the fuel assembly of Figure 1) for BU = 0 MWd/tonU.

As it can be seen from Figures 3–5 good agreement is obtained in the evolution of the most relevant isotopes for both models.

In addition, the radial distribution for ^{155}Gd in the poisoned pin at 2000MWd/tonU has been calculated with both models for each radial zone. The results are shown on Table 3.

As it can be seen, the results for radial distribution of ^{155}Gd obtained are consistent between models and reported values.

Finally, the thermal flux profile in the horizontal direction (x) of the fuel assembly is compared for two burnups

for two vertical positions (measured in cm where $x, y = 0, 0$ is the centre of the fuel assembly of Figure 1). The results are shown on Figures 6 and 7. These results are not reported on the benchmark.

The results obtained for thermal flux profiles show a fairly good agreement between both codes, even when the

FIGURE 7: Thermal flux profiles on both models for two different vertical positions ($x, y = 0, 0$ is the centre of the fuel assembly of Figure 1) for BU = 4000 MWd/tonU.

fuel assembly is evolved to 4000 MWd/tonU. As far as the averaged zones do in which flux is obtained do not match exactly, slight differences are encountered.

4. Conclusions

The results obtained with the *Serpent* code for this simple benchmark show a fairly good agreement with reported values and with those calculated with INVAP's cell code *Condor*. The main results regarding reactivity, isotope evolution, and flux profiles show a good agreement, which encourages the future test of the code in other problems, such as more complicated geometries. The next step would be the generation of few group constants to be used in core calculations.

Furthermore, as far as the *Serpent* code is a cell-oriented code, the running time is accessible. Nevertheless the running time involved is much bigger than *Condor* (2D collision probability code).

A future work will involve the test of *Serpent* code in MTR type fuel assemblies to obtain few-group constants generation and perform core calculations.

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