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Macroscopic Cross Section Generation using WIMS-ANL/ Parcs 2.4 codes –-Comparison with BEAVRS-PWR Benchmark

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1. Introduction

Simulations of the reactor core are essential for the economical and safe operation of a nuclear plant. Currently, several different simulation tools are available and nuclear engineers perform calculations to predict the state of the reactor's core. This work is an example of computational tools applied to perform pressurized water reactor (PWR) simulations. Currently, the complete analysis of the core of a nuclear reactor is still based on the traditional two-step calculation scheme, which has been the standard approach for reactor analysis. These steps consist of: (1) spatial homogenization and condensation of energy groups using cell code, and (2) calculation of the complete core in 3D using few group constants, generated in the previous step. Samchez's work [1] provides a good review of modern homogenization techniques.

In any two-step simulation, the calculation of the macroscopic cross sections is essential to obtain satisfactory results. There are many methodologies and codes to find these values. One of the most used codes is the WIMS code, which has a group of methodologies to obtain homogenized macroscopic cross sections. In this sense, this work aims to obtain the macroscopic cross sections with WIMS-ANL and use them to simulate the whole core using the PARCS2.4. To validate the methodology used in this work, the BEAVRS benchmark was considered.

BEAVRS was published in 2013 by the Computational Reactor Physics Group of the Massachusetts Institute of Technology (MIT) and has been updated several times. The benchmark specification contains a detailed description of an unknown (real) nuclear power plant with a Westinghouse PWR reactor. The documentation contains details of Hot Zero Power (HZP) measurements and reactor operating conditions for the first and second fuel cycles.

2. Methodology

The methodology consists of two stages. In the first step, the macroscopic cross sections of the fuel assembly (FA) with WIM-ANL will be calculated. In the second stage, the cross sections obtained will be used to simulate the entire reactor with the PARCS 2.4 code; these simulations are made for the reactor's Hot Zero Power (HZP) and the first cycle of operation.

2.1 Obtaining macroscopic cross sections

The WIMS code family allows the calculation of neutron flux distributions, k-inf and k-eff values in a variety of reactor. Tipically, the WIMS-ANL reactor physics code has been used as a tool for lattice calculations to generate homogenized reactor physics parameters for a whole core (i.e. traditional two-step analysis)

In this work, the MULTICELL method will be used. The MULTICELL approach is only an alternative but offers an additional possibility that any of the cells in Fig. 1a can also be a group of pin cells by themselves. Any of these cells, which for some reasons are considered different from the others, can be calculated independently. The calculation is performed separately for each cell type, but the usual boundary condition is replaced by "intercellular boundaries" expressed in terms of the probabilities that a neutron will leave one cell type and enter another. This is expressed schematically in Fig. 1b, where the cells were separated for the calculations and their interconnections must be provided from outside. Fig. 1c illustrates that cell types can differ not only in composition but also in dimensions [4].

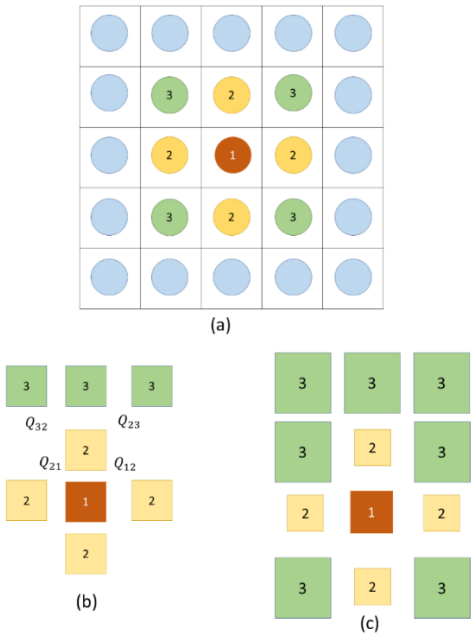

Figure 1: Schematic interpretation of the MULTICELL approach (a) - Macrocell to be calculated with the cell types chosen (b) - The calculation of the spectrum of 69 groups is carried out separately for each type, (c) - The cells may differ in composition and geometry.

2.2 Reactor core model with PARCS

The model proposed in this work will have the same radial nodalization as the standard load of the reactor core (BEAVRS core), a node for a FA and a total of 257 nodes. The axial nodalization consists of 19 axial levels of active core of equal length and two reflecting nodes, upper and lower (See Fig. 2b).

Another model has been added for the axial and radial reflector. The suggestions made in the WIMS user manual for simulating reflectors were used [3]. In order to simulate the radial reflector, the FA in gray (see Fig. 2), was applied as an additional square region, having the same size as the other FA (Fig. 2). And it is filled with 2 regions: water and steel (Stainless Steel). In addition, for the sake of simplicity and to reduce computational effort, the spacer grid models were not considered.

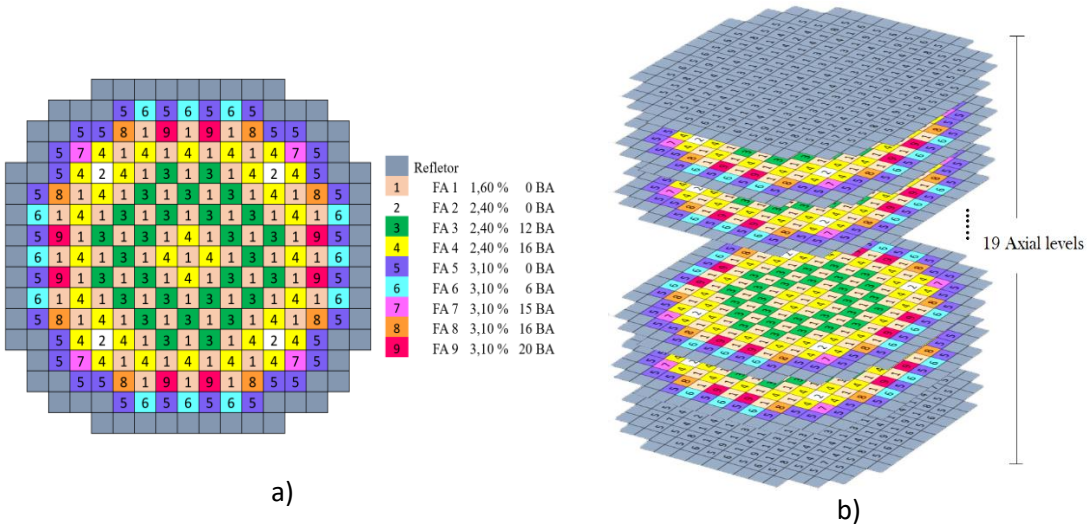

Figure 2: a) Radial profile modeled on PARCS of BEAVR, b) Axial profile of the core modeled on PARCS.

3. Results and Discussion

The first step consisted of obtaining the macroscopic cross sections, to later use them in the simulation of the complete reactor with the PARCS code. Due to the large amount of data from the cross sections, in this section it will present only the k-eff values for Hot Zero Power state, this to show that the values are consistent, some of which have been compared with other studies. In this first stage, the configuration of cycle 1 [2] was simulated, which consists of FAs with different enrichments and different numbers of BAs in each FA, as shown in Fig. 2a. All these values are shown in Table I.

Table I: k-eff results for the different FA, obtained with the codes WIMS-ANL, nTRANCER and McCARD [5].

FA	w/o U235	BA	WIMS-ANL	nTRACER	McCARD	Dev.Std
FA 1	1.6	0	0.989864	0.99340	0.99483	0.0025563
FA 2	2.4	0	1.130619	1.13696	1.13751	0.0038296
FA 3	2.4	12	1.006204	1.01318	1.01432	0.0043938
FA 4	2.4	16	0.972506	0.97454	0.97597	0.0017407
FA 5	3.1	0	1.211479	1.21971	1.21971	0.0047521
FA 6	3.1	6	1.127674	1.16273	1.16313	0.0203560
FA 7	3.1	15	1.065516	1.07835	1.07895	0.0075888
FA 8	3.1	16	1.059016	1.06340	1.06416	0.0027766
FA 9	3.1	20	1.021857	1.02769	1.02886	0.0037513

The PARCS core model has the same radial nodalization as the reactor core loading pattern (Fig. 2). Fig. 3 shows the axial distribution of the detector measurements (orange circles) provided with the BEAVRS specification (Hot Zero Power condition), it also shows the values that were calculated with PARCS (blue circle). It can see that these points are quite like each other.

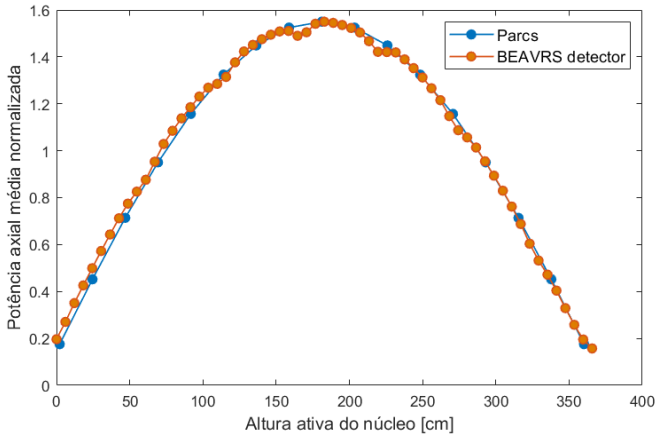

Figure 3: Distribution of axial power of BEAVRS (orange dots). Axial power distribution calculated by PARCS (blue dots).

Fig. 4 shows the boron concentration history throughout the burnup for the first cycle of reactor operation. Figure 4 shows the data obtained with WIMS-PARCS and the data measured by the detector is also presented.

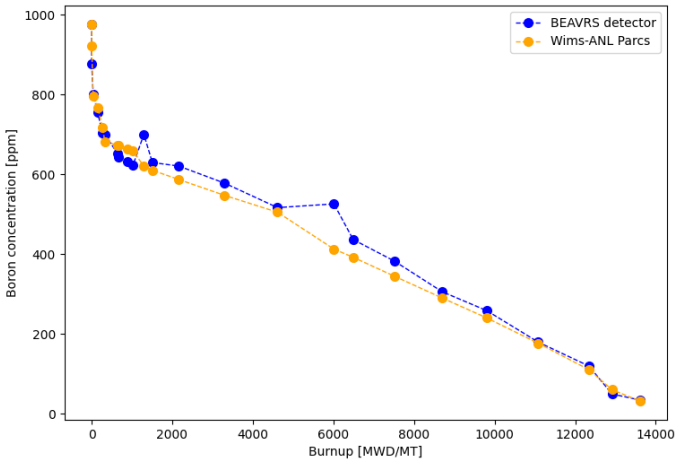

Figure 4: Comparison of the boron measurements [2] performed during Cycle 1 with WIMS-PARCS calculations.

4. Conclusions

The data specified in the BEAVRS were used to simulate the reactor core, which consisted of two stages. The first step consisted of calculating macroscopic cross sections, these data were obtained with the WIMS-ANL code. With the model used in WIMS-ANL, the k-eff of each fuel assemblies were calculated; the maximum standard deviation of the results was 0.02. The second step is to use the cross sections in the PARCS input file, in order to obtain the distribution of axial. The boron concentration was also obtained throughout the burnup during the first cycle of operation.

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