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Methodology for Predicting Initial Core Loading of Research Reactors Using Neutron Flux Ratios

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Abstract – *Research reactors initial core loading have different U-235 masses in each region to increase burnup rate and decrease the power peaking factor (PPF). Initial core U-235 mass loading distribution of research reactors is usually calculated using deterministic methods of computation that is based on burnup calculations which would consume a lot of time using Monte Carlo methods. The aim of this work is to predict the initial core U-235 mass loading distribution by calculating the flux ratios between the core regions rather than the conventional burnup method. An analysis of the two methods was performed in this paper and it was found that the proposed method (using MCNP5) showed more accurate results than that of the burnup method (using MCNPX) in less runtime and reasonable runtime compared with the deterministic methods approach.*

I. INTRODUCTION

Research reactors initial core loading have different U-235 masses in each region to increase burnup rate and decrease the power peaking factor (PPF). Starting from a ratio equals to 1 between the masses of U-235 in all regions we can reach the equilibrium core after burning several cores and get the ratios between U-235 masses which is the initial core loading ratios [1].

Using MCNPX to calculate the burnup until reaching the equilibrium core takes a lot of time which could be reduced if the flux is calculated instead of the burnup.

II. DESCRIPTION OF THE ACTUAL WORK

The aim of this work is to predict the initial core U-235 mass loading distribution by calculating the flux ratios between the core regions rather than the conventional burnup method. Assuming that the local burn up is almost constant in each of the 3 regions of the core for each cycle. The fission rate then will depend on neutron flux distribution above the 3 regions radially.

Applying the same shuffling strategy we can reach to the ratios between masses using ratio between neutron fluxes at the equilibrium core, ratio between those fluxes will give an indication about what the masses of initial core loading should be.

1. Methodology

Figure 1 shows the MCNP [2] model used for describing the hypothetical core upon which the analysis was performed.

The core consists of 6x6 IRT-4M fuel [3] using U_3O_8 fuel, no control rods as analysis was performed for a clean core.

Figure 2 shows the shuffling scheme used in both burnup analysis and flux ratios method analysis. The core was divided into 9 regions as shown in figure 2. Each region consists of 4 assemblies, each region was assumed to be having the same burnup. In flux ratios method flux was averaged on each region.

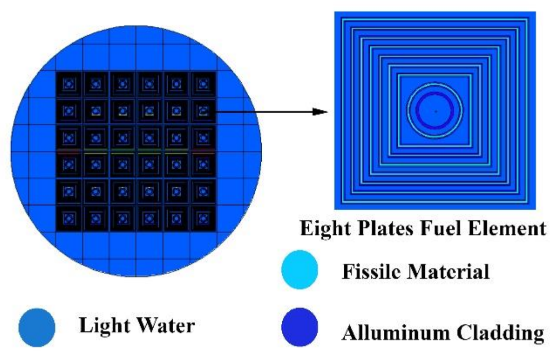

Figure 1. Hypothetical Core MCNP Model

Since all the fuel elements have the same moderator to fuel ratio by volume, therefore burnup will be a function in the neutron flux.

The analysis of the calculated flux distributions over the whole 9 cores has shown that the average flux distribution over the whole 9 cores had the minimum standard deviation in the center region. This is shown in Table 1 for the first core and it remains the same for the rest of the analysis, hence the Burnup at the center region was taken as a reference in the whole analysis and the burnup in any region is calculated only from the flux ratio between the center and the desired region as shown in equation 1.

$$\frac{B_c}{B_r} = \frac{\phi_c}{\phi_r} \tag{1}$$

Where B_c is the burnup percentage in the center region, B_r is the burnup in the n region (i.e. around center 1, around

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center 2 …etc), $\emptyset_c$ is the average neutron flux in the center region and $\emptyset_r$ is the average neutron flux in the n region.

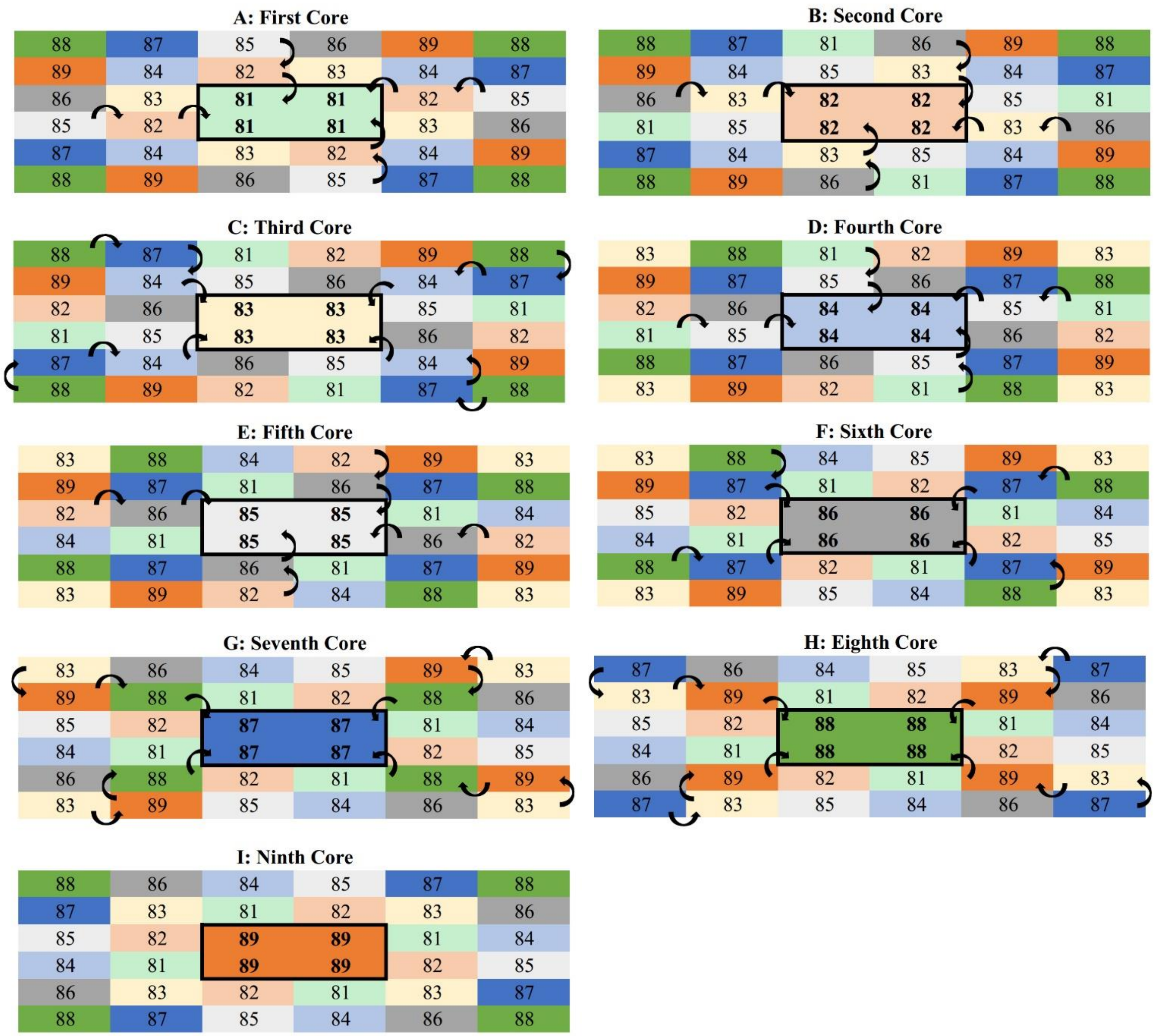

Figure 2. Shuffling Scheme to the Equilibrium Core

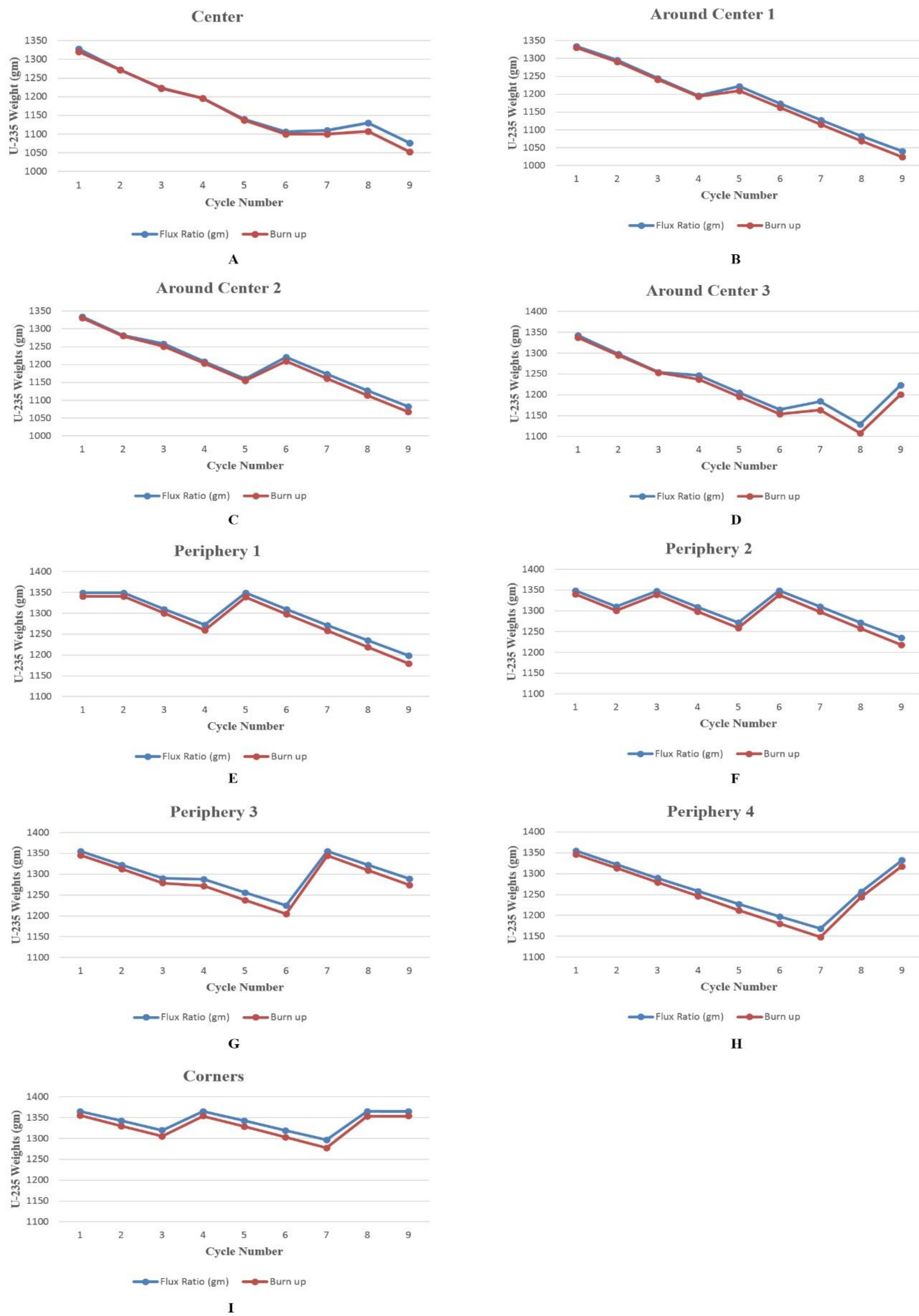

Figure 3. U-235 mass in each region through the 9 cycles using both burnup method and proposed flux ratios method.

Table 1. Average Neutron Flux (n/cm^2.sec) and Standard Deviation (n/cm^2.sec) for Each Region In the first core

Region	Assembly Number	Average	Standard Deviation
Center	81	2.47E+14	1.53E+13
Around Center 1	82	2.11E+14	3.30E+13
Around Center 2	83	2.10E+14	3.24E+13
Around Center 3	84	1.79E+14	3.76E+13
Periphery 1	85	1.53E+14	3.48E+13
Periphery 2	86	1.54E+14	3.42E+13
Periphery 3	87	1.30E+14	3.67E+13
Periphery 4	89	1.31E+14	3.57E+13
Corners	88	8.94E+13	3.71E+13

III. RESULTS

In all regions the two curves are almost identical for the first 3 cores at least, as xenon has not been built with enough mass to affect the burnup as shown in figures 3.A, 3.B, 3.C and 3.D respectively. A slight difference might be observed in the periphery regions than the center and around center regions shown in figures 3.E, 3.F, 3.G, 3.H and 3.I, this is because during the travel of neutron from the center and around the center regions it passes through the Xenon produced through the two regions until it reaches the periphery region.

U-235 masses in case of burnup method is less than that of the flux ratios method. This is due to the xenon buildup leading to the increase in U-235 burn in order to compensate the neutron loss in xenon to maintain the power constant

The maximum difference between the two methods got while predicting the masses of U-235 during the 9 cycles is shown in table 2.

Since each region consists of 4 fuel elements, therefore the maximum difference between the two methods for each fuel element is approximately 5 gm U-235. Since the typical U-235 masses in research reactor is in terms of E2, therefore the difference between the two methods can be expressed as approximately 5% of the fuel element mass.

Table 2. Maximum Difference in U-235 masses for Each Region during all cycles

Region	Maximum Difference (gm)
Center	23.713
Around Center 1	16.02
Around Center 2	14.46
Around Center 3	20.9412
Periphery 1	19.99
Periphery 2	17.43
Periphery 3	20.16
Periphery 4	20.24
Corners	19.24

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Table 3 shows the 3 regions ratios relative to the center region using both the burnup method and the flux ratio method. Each region has the same loading for each fuel element, therefore based on the preliminary calculations of critical mass U-235 distribution in the core can be calculated from the ratios using table 3 using the following formula in equation 2.

$$\frac{Mass}{Region} = Critical\ Mass * \frac{Region\ Ratio}{\sum_{Region} Region\ Ratio} \tag{2}$$

Where the $\frac{Mass}{Region}$ is the U-235 loading mass in each region and the *Region Ratio* is the calculated ratio of U-235 mass relative to the center region.

Table 3. Initial Core U-235 Loading Ratios in the Three Regions

Region	Burnup	Flux Ratio
Center	1	1
Around the Center	3.127	3.107
Periphery	6.024	5.964

IV. CONCLUSIONS

From the above discussion it was observed that the flux ratios method will result the same results coming from the burnup method. Reaching the equilibrium core using the conventional burnup method using the least possible time steps and number of histories took 108 hours of runtime, on the other hand the flux ratios method took only 9 hours of runtime. Using flux ratios method a lot of time can be saved instead of extremely long runtime burnup methods. Another advantage of the proposed methods is that it can give more accurate prediction of the initial core loading as it does not count for the xenon build up in its calculations, which is the real case of the initial core loading as in most of the research reactors initial core loading does not include poisons.

Usually initial core loading of a research reactor is optimized and determined using a deterministic method of computation, using the above described flux ratio method for the same moderator to fuel ratio, Monte Carlo based computations can be used in such task resulting more accurate results than that of the deterministic methods in reasonable runtime.

Future work may include modifications on the used formula to include different moderator to fuel ratios also algorithms can be developed to find the optimum shuffling technique for any research reactor using Monte Carlo based computation.

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