

## **DRAGON AND SERPENT 2-D MODELLING OF THE SLOWPOKE-2 REACTOR AT ÉCOLE POLYTECHNIQUE MONTRÉAL**

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### **Abstract**

DRAGON is a deterministic code that can be used to perform lattice cell calculations based on numerical solutions of neutron transport equation. DRAGON can also be used for full core 2-D and 3-D simulations in transport. One alternative to the use of such a deterministic code consist in following the history of neutrons in the core based on statistical Monte Carlo simulation with codes like MCNP and SERPENT. This second calculation approach has been used successfully for SLOWPOKE-2 simulation in the past. Here we present a comparison between DRAGON and SERPENT calculations for the SLOWPOKE-2 reactor. We also compare the flux distribution obtained using both codes for a copper sample placed inside a small irradiation site.

### **1. Introduction**

Since 1976, a SLOWPOKE-2 reactor has been in operation at École Polytechnique de Montréal [1]. This reactor is safe and licensed to operate unattended. It was initially fuelled with less than 1 kg of highly enriched uranium (HEU), in the form of uranium-aluminum alloy. In 1997, it was refuelled using uranium enriched at 19.76% in the form of uranium-oxide fuel [2, 3].

Local flux distributions in the SLOWPOKE-2 are difficult to evaluate experimentally due to the complexity of the core and the difficulty to place detectors at a sufficient number of position in the reactor to provide accurate maps of the flux. DRAGON 2-D simulation of this reactor have been performed and seems to provide good results [4, 5], however, in order to check the reliability of these calculations, a comparison with a code that uses totally different methods of calculation was suggested. Here for this comparison we will use the SERPENT Monte Carlo code [6].

In Section 2 of the paper we first present the SERPENT calculation models that have been used to generate the thermal and epithermal flux distribution in the whole reactor. In Section 3 we describe the equivalent DRAGON calculation models while in Section 4, a comparison of the DRAGON and SERPENT results is provided. Finally in the last Section we conclude.

## 2. The SERPENT calculation

### 2.1. The geometry

Building a model of the SLOWPOKE-2 geometry for the SERPENT code is a two level process. On the first level, a cell geometry that contains seven concentric annular regions located inside a Cartesian region is considered. The annular regions that start with the inner central water hole (control rod position without the mechanism inserted), and finish in a pool that extends to 35.56 cm (See Fig. 1) are explicitly represented [3]. Superimposed over this first level, one finds annular pins that correspond to irradiation sites and fuel elements. For simplicity, reflective boundary conditions were selected at the limits of the pool.

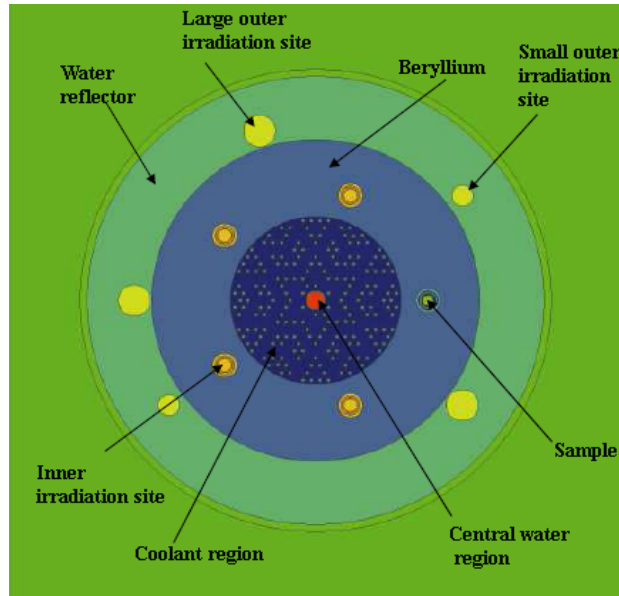


Figure 1: SERPENT geometry for the SLOWPOKE-2

The SLOWPOKE-2 reactor contains 198 fuel elements (fuel pins) containing uranium oxide that are distributed on a hexagonal mesh (hexagonal lattice of pitch 1.1036 cm). In order to evaluate with sufficient spatial precision the flux distribution inside a sample, the annular region that correspond to these sites were further discretized. In fact the site was subdivided annularly into 4 regions in addition to being cut in half by a line passing through the center of the sample and perpendicular to the line joining the center of the core and that of the site (See Fig. 2). These subdivisions were created using the SERPENT “pad” option.

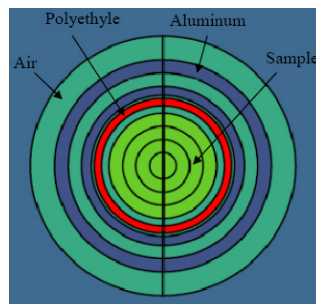


Figure 2: Fine mesh subdivision of irradiation tube

## **2.2. SERPENT sequences of calculation**

In order to generate a complete SERPENT input file, the mixtures located inside each region must be defined. Here, we used the information provided in Guertin thesis [4, 5]. The temperature of all the mixtures is assumed uniform and set to 300 K. The cross sections were taken from an ENDF/B-VII library. In order to achieve results with adequate accuracy, we selected a population of  $10^5$  neutrons per cycle and considered 500 cycles.

Since for comparison with DRAGON we look at the thermal and epithermal neutrons flux, a condensation to a two groups energy structure was used for the output. Moreover, 22 flux detectors were placed in the universe of irradiation site 1, eight of them being inserted in the sample itself.

## **3. DRAGON simulation**

### **3.1. Geometry models**

Here we have considered the same global geometry as that defined for SERPENT (See Fig.1). The main differences are that the seven regions of the first level are specified by a CARCEL option that generate a two dimensional Cartesian cell with embedded annular regions. In addition, these annular regions are further subdivided into respectively 5, 1, 48, 50, 41, 4 and 25 sub-regions of equal thickness in order to ensure the convergence of the radial flux distribution inside the core [4].

The fuel pins, the inner irradiation sites inside the beryllium reflector and the outer sites in the water reflector are inserted as pin cluster in the global annular. Moreover the inner site 1 that contains the sample is subdivided following the same procedure as in for SERPENT model (See Fig. 2).

Finally the mixture used to fill the various reactor regions are taken at a temperature of 300K [5]. A low enrichment (19.76 % U-235 in U)  $\text{UO}_2$  fuel is again considered.

### **3.2. DRAGON sequences of calculation**

In order to compare our two models, an ENDF/B-VII based WLUP library was selected [7]. The sequence of module used for this straightforward DRAGON execution is showed in Diagram 1. Here the NXT: module was used to generate tracking information. The collision probability matrices were then built using the ASM: module. The macroscopic cross section library was generated using the LIB: module based on an ENDF/B-VII library with resonance self-shielding calculations performed with the SHI: module. The flux files were then produced by the FLU: module. Homogenization and group condensation were carried out with the EDI: module that produces the final output file.

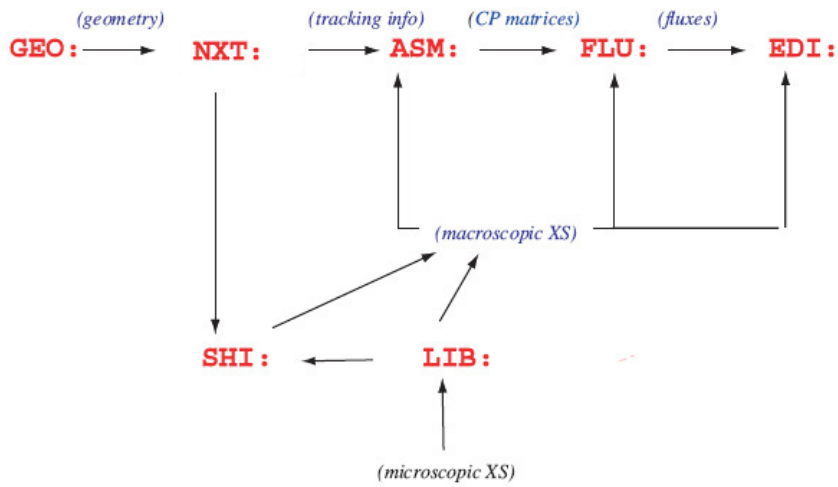


Diagram 1: DRAGON calculation sequence

## 4. Results and discussion

### 4.1. Core flux distribution

In order to check the results of the DRAGON simulation, we take SERPENT as the reference code. Illustrated in Fig. 3, one can find cartography of neutrons collisions sites in the reactor provided by SERPENT (each collision is represented by a white spot).

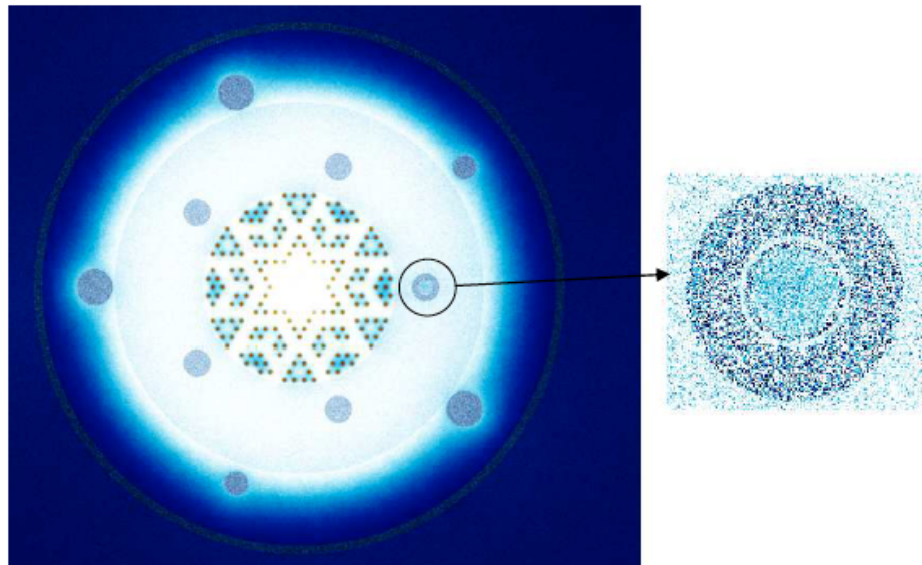
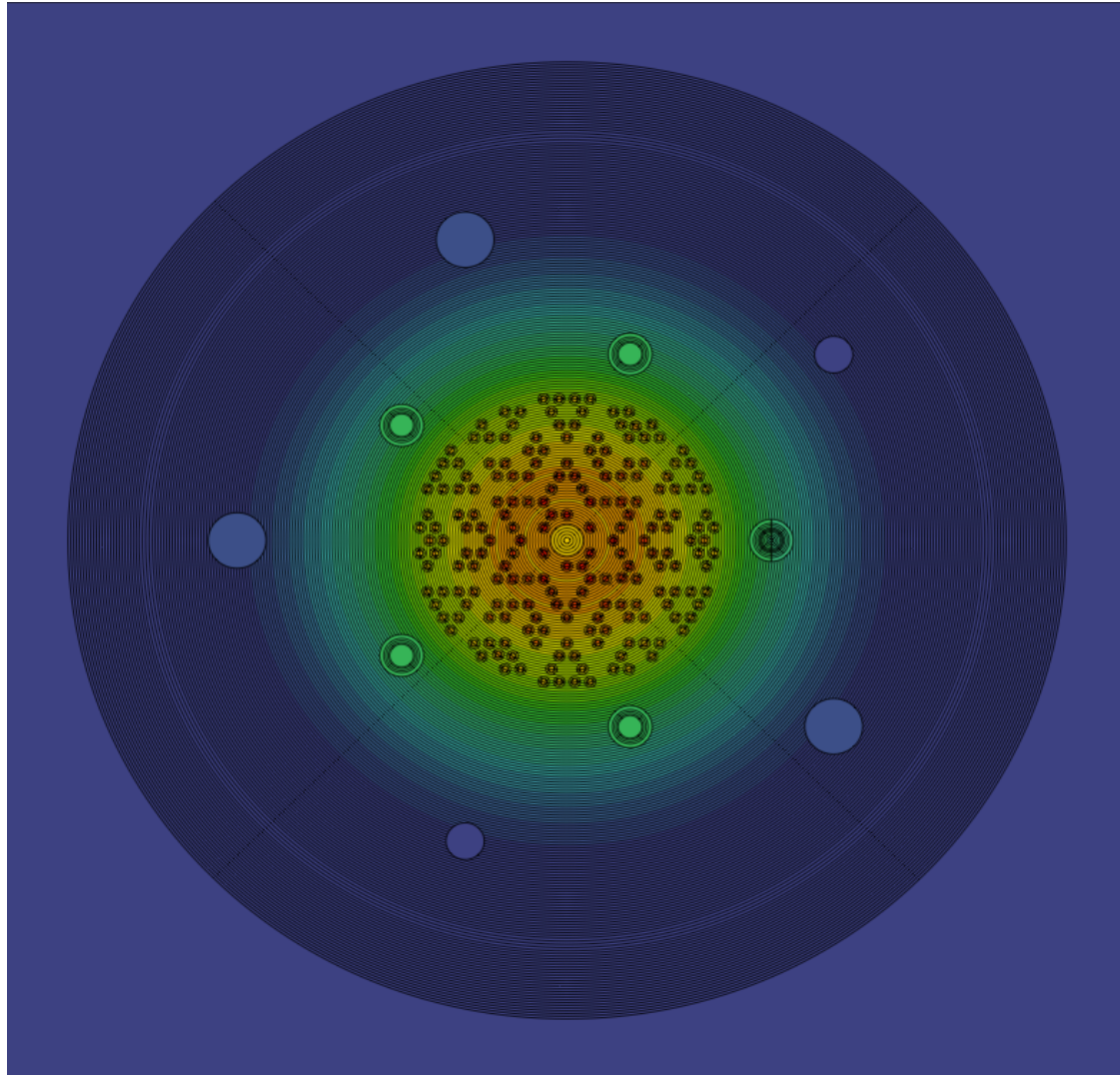


Figure 3: SERPENT cartography of neutron collision sites in the SLOWPOKE-2. On the right neutron distribution in inner site 1 filled with copper.

Contrarily to SERPENT, DRAGON associates with every mesh region an average flux. So, as we increase the number of regions in the model, more accurate results are obtained.

Here, the SLOWPOKE-2 reactor is subdivided into 330 regions and calculation results are condensed to two energy groups, the thermal and epithermal flux thus obtained being illustrated in Fig. 4 and 5. As one can see, the fast neutrons are mainly generated in the fuel region (80 %) before being slowed down in the water moderator and the beryllium.



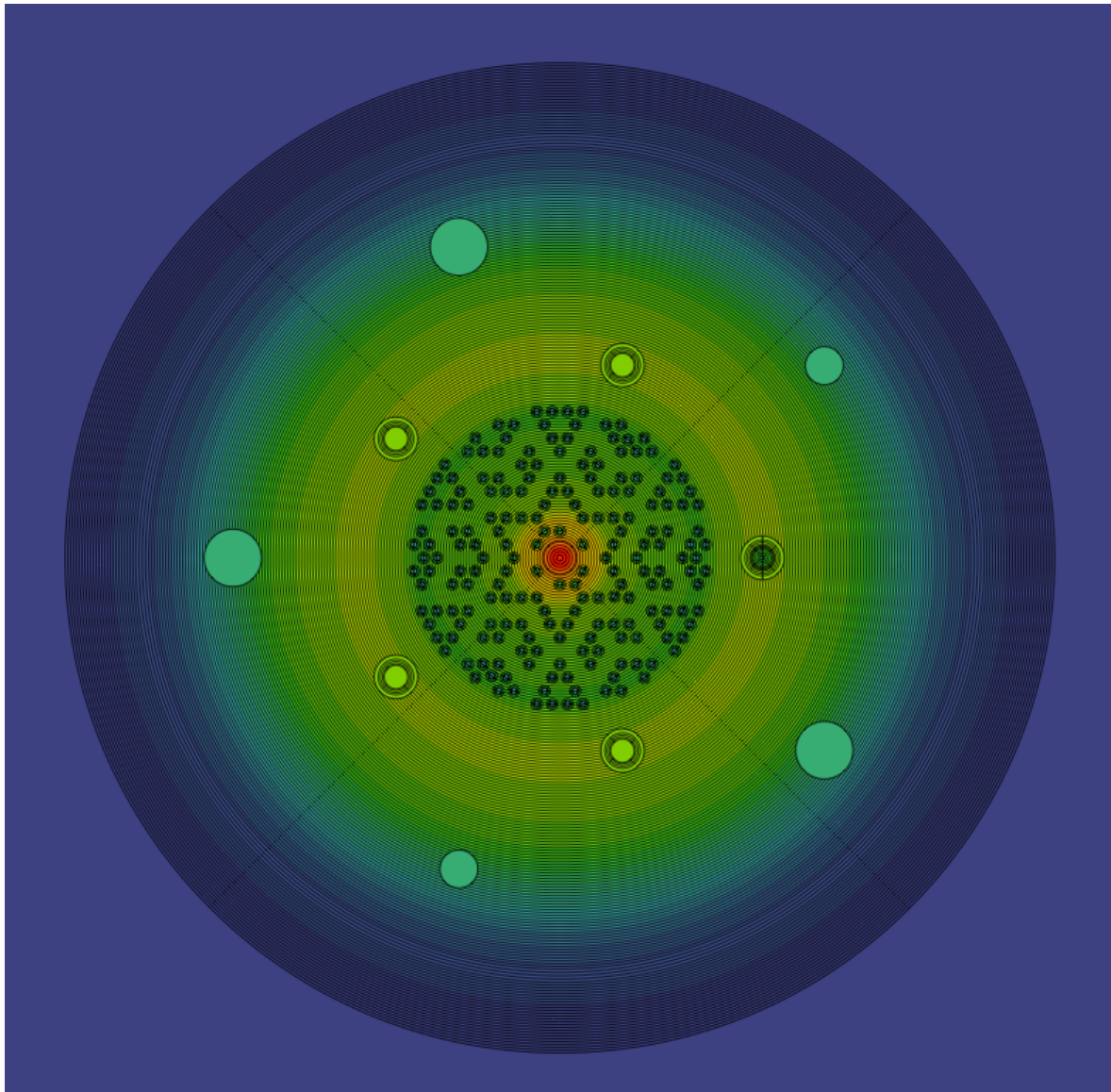
*Legend*

*Color by Flux: cond. group 1*

$3.08E-01 + (i-1) * 1.16E+01 < Flux(i) \leq 3.08E-01 + i * 1.16E+01$



Figure 4: Epithermal flux in SLOWPOKE-2 reactor with  $i$  the color region given by the color bar



*Legend*

*Color by Flux: cond. group 2*

$2.02E+00+(i-1)*5.73E+00 < Flux(i) \leq 2.02E+00+i*5.73E+00$



Figure 5: Thermal flux in SLOWPOKE-2 reactor with  $i$  the color region given by the color bar

In Fig. 6 the radial fluxes distribution computed by DRAGON in the SLOWPOKE-2 reactor is presented. Note that in the fuel region, only the flux in the water moderator is illustrated. As expected, the thermal flux is higher in the central region, which contains only water, than in the fuel region where the epithermal flux dominates [8]. We also observe an increase in the thermal flux in the beryllium due to the reflection of fast neutrons in this region of the core. After the beryllium region both the epithermal and thermal neutrons decreases rapidly due to neutron capture and leakage.

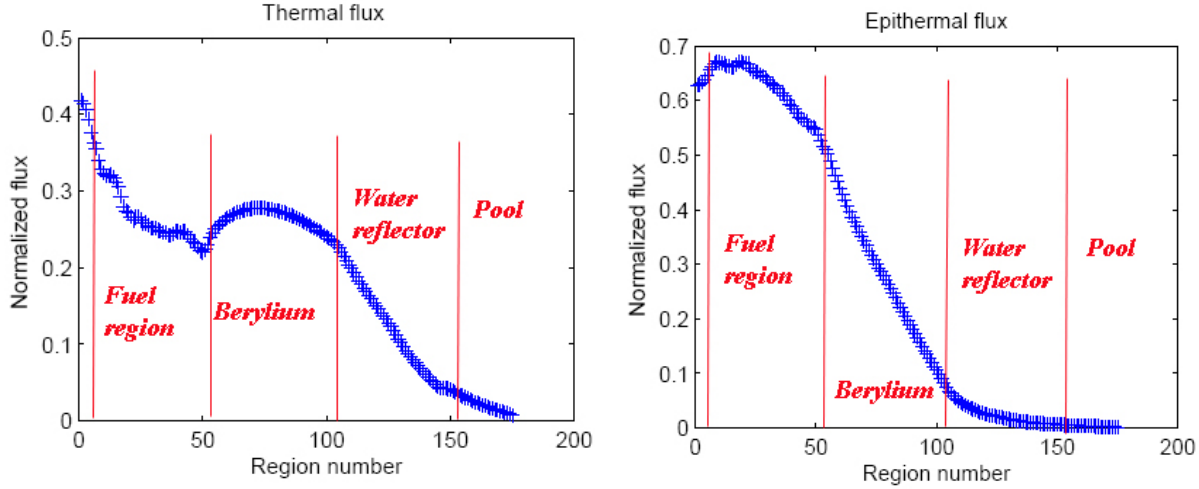


Figure 6: DRAGON epithermal and thermal flux variations in first level geometry of SLOWPOKE-2 reactor.

#### 4.2. Sample flux comparison

Cylindrical copper sample of height 3 cm and radius 0.635 cm were simulated in both codes. In order to compare DRAGON and SERPENT fluxes inside and around the sample, SERPENT fluxes was normalized by total flux at end of site 1 facing the reactor core, then DRAGON fluxes normalized by ratio of average SERPENT flux and average DRAGON flux (See Eq. 1)[2, 8].

$$\phi_{gi}^{DN} = \phi_{gi}^D \frac{\sum_g \sum_i V_i \phi_{gi}^S}{\sum_g \sum_i V_i \phi_{gi}^D} \quad (1)$$

where  $\phi_{gi}^D$ ,  $\phi_{gi}^{DN}$  and  $\phi_{gi}^S$  are respectively the DRAGON flux, the normalized DRAGON flux and the SERPENT flux in region ( $i$ ) and for group ( $g$ ).

Splitting the irradiation site 1 into 22 regions the regions are numbered from the outer radial region facing the fuel to the outer radial region facing the water reflector (See Fig. 1).

Fig. 7 and 8 illustrate the flux distribution of both codes for all regions in irradiation site 1. As can be seen, the deterministic calculation of DRAGON results in a very similar fluxes distribution as that produced by SERPENT. Thermal flux shows the same variations for both codes but a 13.3% difference between flux profiles is observed. Similarly, the shape of the epithermal flux for both codes is very similar but with a 9.3% offset.

Here, the epithermal flux decreases from the region near the fuel to the water reflector. This reduction was due to neutron slowed down in Beryllium. Further, the thermal flux decreases

quickly towards the center of the sample and then increases back in the region facing the water reflector. The decrease is due to the important thermal absorption cross section of copper which leads to few neutron being able to reach the center of the sample. The flux increases being the result of neutrons slowing down in the beryllium that are reflected back into the sample (See Fig. 7).

We can also see that the presence on strongly absorbing copper in the sample also affect the flux in the surrounding regions.

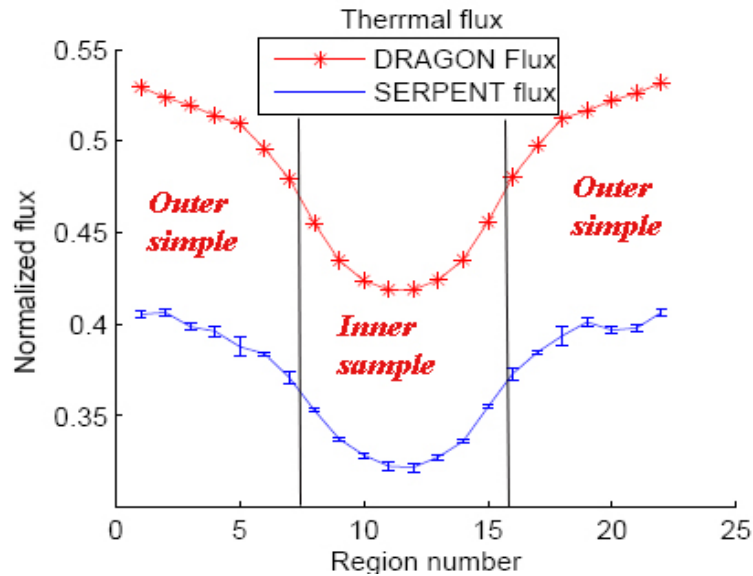


Figure 7: Comparison of SERPENT and DRAGON thermal fluxes in small site 1

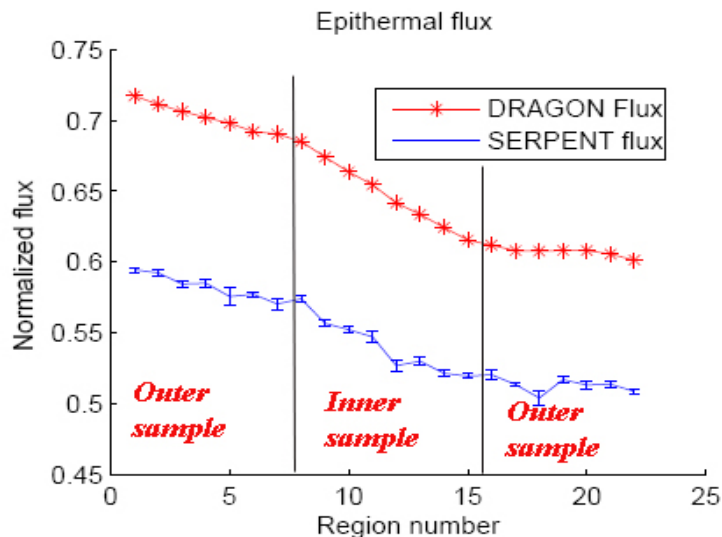


Figure 8: SERPENT and DRAGON epithermal fluxes in small inner site 1

## 5. Conclusion

The comparison of SERPENT and DRAGON models has shown a good agreement for the two-group neutron flux distribution both in the core and at the detector site. This comparison confirms that DRAGON can provide an adequate flux distribution even in the small SLOWPOKE-2 irradiation sites. This will be useful for neutron activation analysis (NAA) to evaluate the spatial self-shielding effect caused by strongly neutron absorbing sample. The next step is to consider simplified simulation models for the SLOWPOKE-2 reactor in such a way as to decrease DRAGON CPU requirements. We are also looking at comparing 3-D SERPENT and DRAGON simulation results for this reactor.

## 6. Acknowledgments

This work was supported in part by University Mission of Tunisia in North America (MUTAN), by the ROASTERS foundation scholarship of École Polytechnique Montréal and by Natural Science and Engineering Research Council (NSERC) of Canada.

## 7. References

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