

## IMPROVEMENTS IN THE BIOLOGICAL SHIELDING OF THE BNCT FACILITY AT THE IEA-R1 REACTOR

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### ABSTRACT

BNCT is a promising cancer treatment technique. It uses the high LET particles from the reaction  $^{10}\text{B}(n, \alpha)^7\text{Li}$  to destroy cancer cells and has shown success where other techniques alone not. The development of this technique began in the mid-50's and even today it is object of study and research in centers around the world and Brazil has built a facility that aims to conduct research in BNCT. This facility is located next to irradiation channel number three at the IEA-R1 reactor and has a biological shielding designed to meet the radiation protection standards. However, at the exchanging samples procedure the background radiation in the experimental room increases and interferes in measurements carried out by other research group that uses a nearby irradiation channel at IEA-R1 reactor. This work presents a set of improvements done in the biological shielding to reduce this background oscillation. To reach this purpose, the MCNP5 code was used to plan these improvements and thermoluminescent dosimeters to evaluate this methodology.

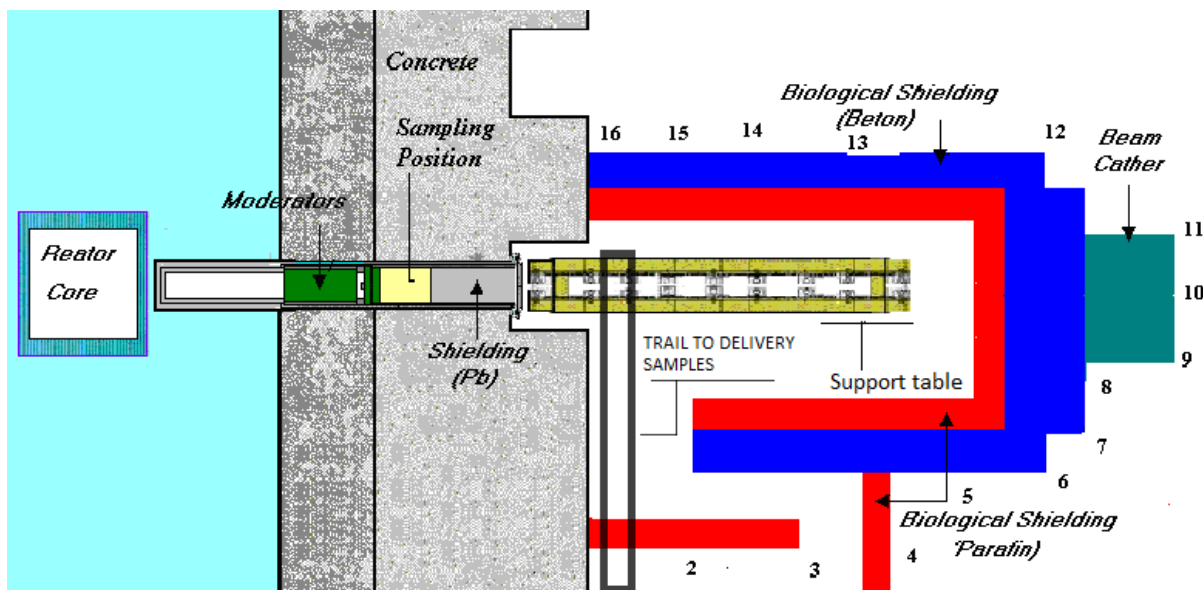
### 1. INTRODUCTION

BNCT is a cancer treatment therapy that uses the  $^{10}\text{B}(n,\alpha)^7\text{Li}$  reaction to kill cancer cells. The therapy is a dual procedure; the first step is to inject a Boron compound that shall be preferentially absorbed by the cancer cells and then submit the tumor area to a thermal neutron beam. BNCT researches began in the mid 50's[1] by the scientific community. In Brazil a research facility was built in the IEA-R1 reactor to perform BNCT experiments. This facility has a biological shielding designed to attain the radioprotection criteria maintaining researchers safe against the strong neutron/gamma field from the reactor. However, when exchanging samples with the reactor at full power, the background radiation varies due to the opening/closing of the BNCT beam hole. This thermal background variation interferes in experiments carried out at a nearby experimental facility. This work aims to improve the BNCT biological shielding and it has been accomplished by designing improvements through MCNP5.

## 2. SHIELDING IMPROVEMENTS

### 2.1. BNCT Research Facility

In order to change samples, the sampling position and the internal lead shielding tube are moved over the support table. After this removal proceeding and with the assistance of a claw guided by an outside trail samples are inserted at the sampling position. Figure 1 shows a schematic top view of the facility and its biological shielding.

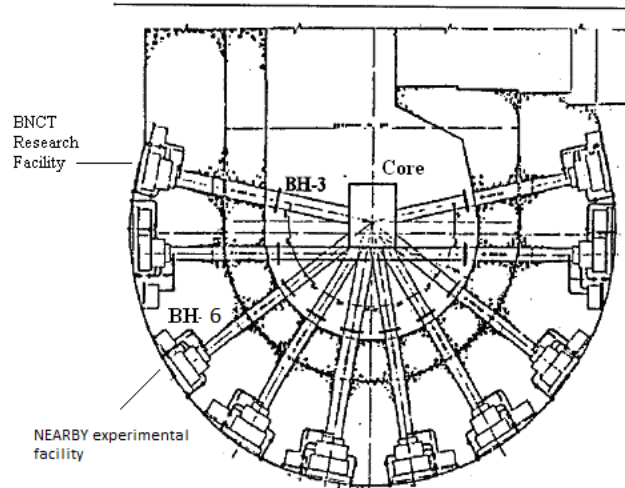


**Figure 1: Schematic top view of the facility built at BH#3 of IEA-R1 Reactor in IPEN**

The biological shielding consists of a set of walls and roof made from paraffin boxes and concrete blocks with the beam catcher standing along the BH#3 axis outside the shielding, as it can be seen in figure 1. Roof and walls are consisted of a 30 cm of paraffin layer followed by a 38 cm of concrete one except for the front wall that is thicker (76 cm of concrete), placed perpendicularly to the beam line .

The gamma ray, neutron and gamma-neutron attenuation factors[2] for the front wall are respectively: 15300; 600 and 3000; for the roof and the remaining walls these factors are: 5100, 350 and 1600. The obtained dose level around the facility attends the radiological protection rules [3]. The sum of the all shielding materials used in the facility is about 35 t and gives an idea of the strong neutron-gamma field inside the facility when changing samples with the reactor at full power.

Figure 2 presents the schematic view of all IEA-R1 beam holes and it illustrates the position of the nearby experimental facility in beam hole #6 near to the BNCT research facility.



**Figure 2: Schematic view of all the IEA-R1 beam holes**

All the improvements done in the biological shielding aimed to reduce the thermal neutron radiation that leaks from the shielding, and it varies the thermal neutron background in those few seconds when the beam hole is opened and then closed for exchanging samples. For this purpose, polyethylene is used as hydrogenous medium[4] to reduce neutrons to thermal energies and with a 1mm cadmium sheet capture[5] them.

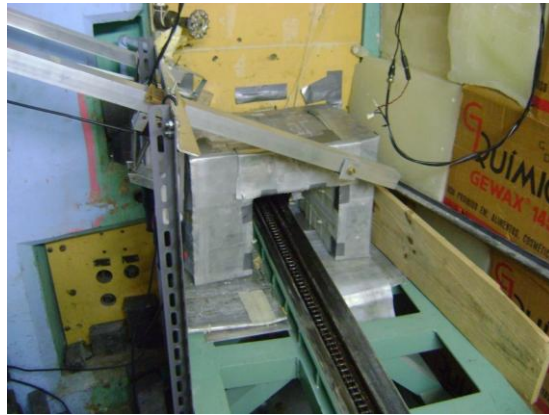
## 2.2. MCNP5 simulations and Improvements Characteristics

The first improvement was planned to be as near as possible to the reactor radiation field and it is designed such as closing beam-hole polyethylene piece that allows only the internal lead shielding tube to be removed. Figure 3 shows this piece at the beam-hole and after it a 1mm same format cadmium cover was put together close to the reactor wall as part of this improvement.



**Figure 3 – Polyethylene shielding piece a the BNCT facility beam hole**

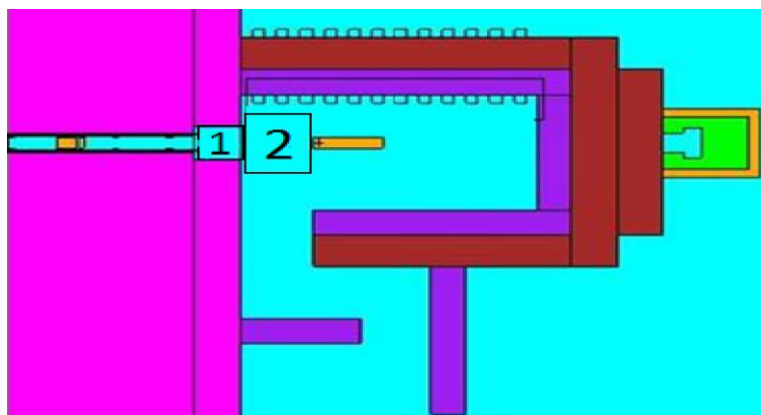
The second and last shielding improvement was a tunnel format piece above the sample inserting/removing table and this improvement is also made with polyethylene and then covered with a 1 mm cadmium blade. With this improvement is expected to restrict the neutron/gamma radiation field from the beam-hole and to reduce the fast neutron field that could emerge from the biological shielding (walls and roof) as thermal neutrons. Figure 4 shows this improvement with the 1 mm cadmium cover already put together.



**Figure 4 – Polyethylene shielding piece with a tunnel format above the sample inserting/removing table**

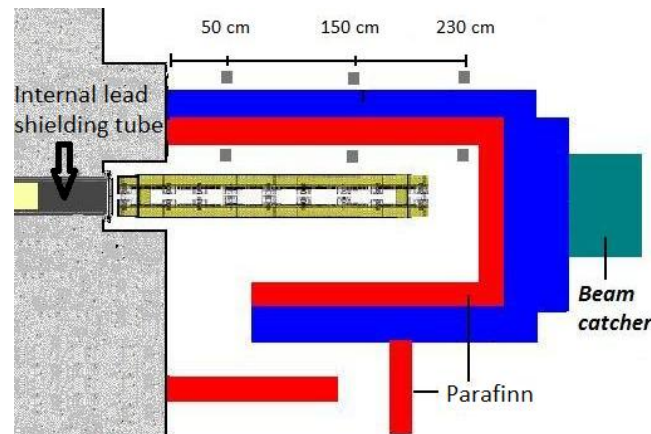
Both improvements effects were simulated with MCNP5 code along with the biological shielding to see the effect they cause at the thermal neutron radiation field outside the BNCT biological shielding. To achieve meaningful results, a neutron source using the Watt-fission spectrum was developed from a surface of the reactor core, this source has no utility to absolute measurements but it is useful to make relative comparisons with improvements and without it.

Figure 5 shows the problem geometry without any improvement added and the tally regions (inner and outer boxes along the left wall of the biological shielding) to calculate neutron fluxes and leakage, tallies were performed only at the left side because it is nearest to other experimental facility.



**Figure 5 – MCNP5 geometric view of the BNCT biological shielding and the regions for both improvements (1 and 2 respectively)**

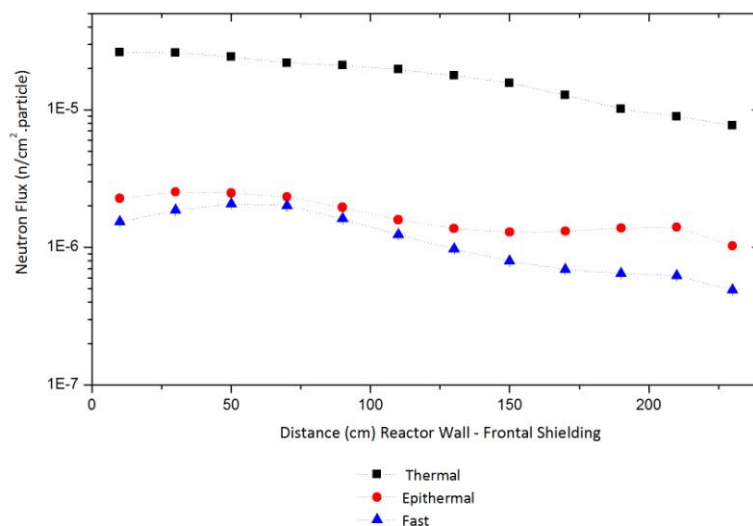
The experimental procedure to evaluate this methodology was done with thermo luminescent dosimeter (TLD 600 and 700). Three points inside and another three points outside the biological shielding were stipulated to perform experiments; figure 6 shows the points in the biological shielding scheme.



**Figure 6 – Points to perform experiments with TLD's.**

### 2.3. Results and discussion

Before adding improvements to the MCNP shielding modeling a non improvement situation was simulated to guide comparisons and the results (three energy ranges) for the neutron flux profile along the inner surface of the left biological shielding wall are presented in figure 7.

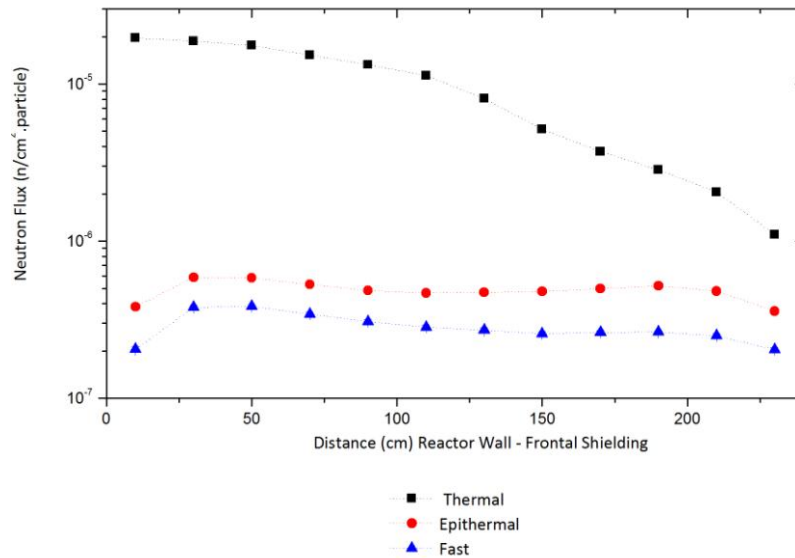


**Figure 7 – Neutron flux profile along the inner surface of the left biological shielding wall without any improvement.**

Thermal neutrons are those with energy lower than 0.5 eV, neutrons with energy in the range of 0.5 eV to 10 KeV is considered epithermal and above this upper limit is considered fast. Figure 7 shows that thermal neutrons is the main contribution in the neutron flux, however, epithermal and fast flux is

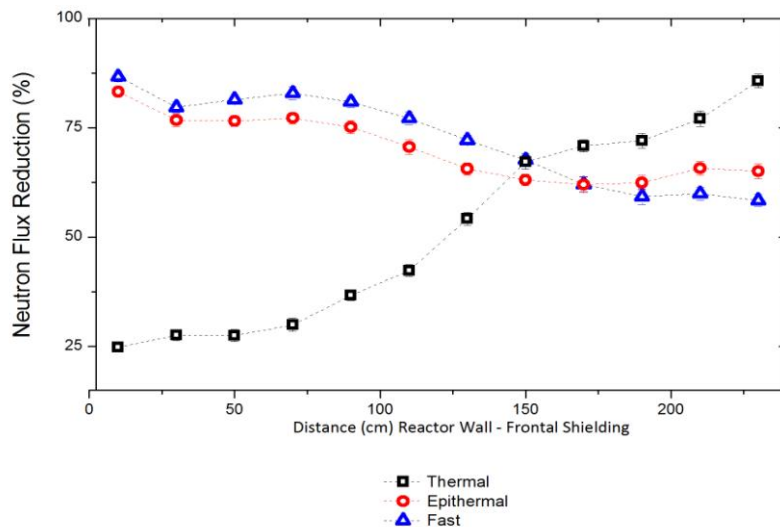
significant and it is the main contributor to the thermal neutrons emerging outside the biological shielding.

It can also be seen, that the internal lead shielding tube when it is in the opening position (see figure 5) stays over the support table (at distance 50 to 60 cm in figure 7) and the lead scatters neutrons with energies above 0.5 eV significantly causing a slight increase in the thermal neutrons flux from this distance on (50~60 cm). After this first work step, an improvement was added to the biological shielding modeling and a new simulation was performed to quantify the effects on the neutron flux. Figure 8 presents these results for the first improvement simulation case.



**Figure 8 – Neutron flux profile along the inner surface of the left biological shielding wall with first improvement added.**

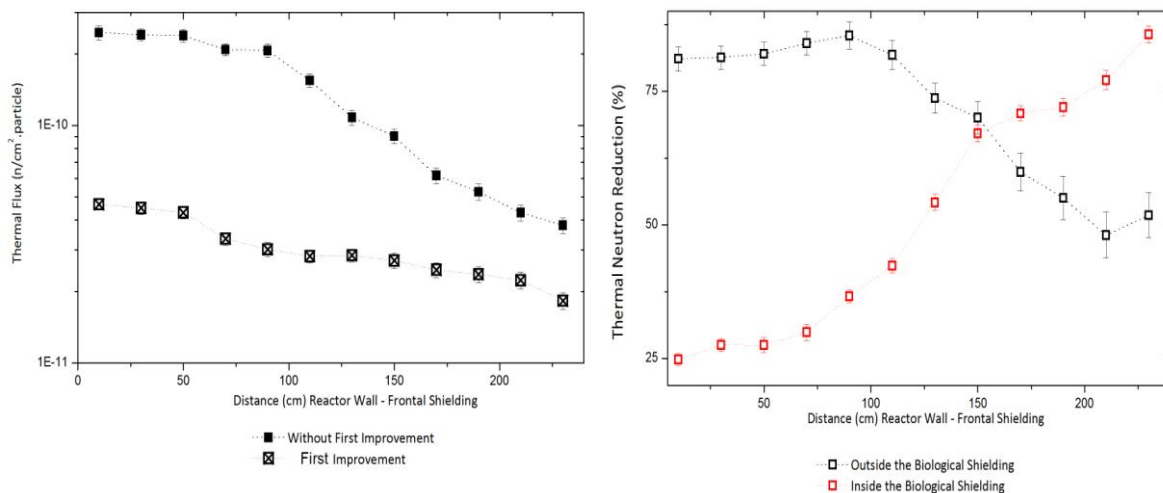
To better understand these results and how the first improvement reduce the neutron flux in all three energy regions an analysis by relative reduction from the no improvements to the first improvement situation is presented in figure 9.



**Figure 9 – Neutron flux reduction due to first improvement.**

In the first centimeters (up to 120 cm) is where best reductions happens for neutrons with energies above 0.5 eV and it also can be seen that the thermal flux reduction increases as the distance from reactor wall to the frontal shielding increases.

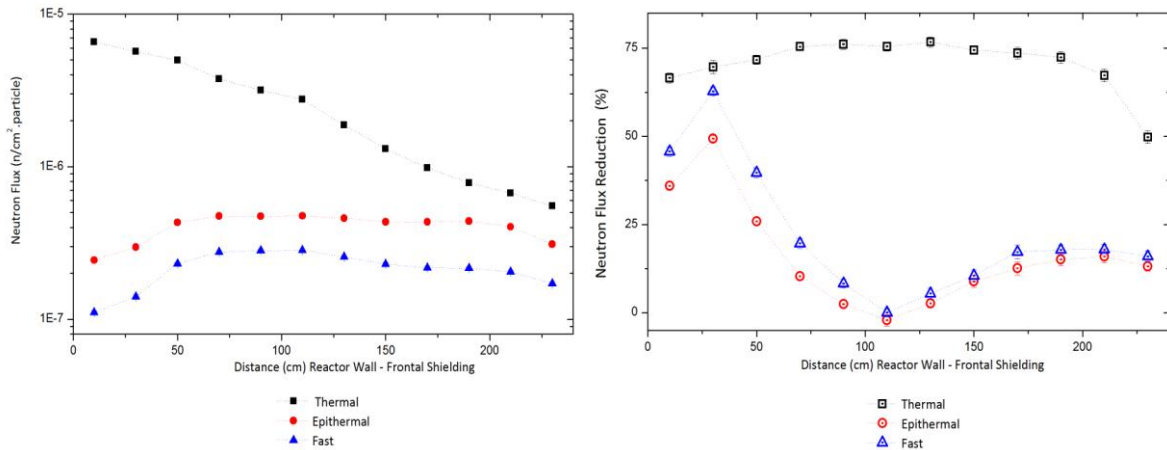
This can be observed because a big fraction of neutrons with energies higher than 0.5 eV, which would be thermalized along the beam path due to scattering in the internal lead shielding tube over the support table and in the paraffin shielding walls, is no longer being thermalized due to the first improvement effectiveness. In the outside of the biological shielding only thermal flux could be calculated with a good acceptance. The thermal neutron flux profile along the outer surface of the biological shielding wall and the relative reduction are shown in figure 10.



**Figure 10 –Thermal neutron flux profile along the outer surface of the biological shielding after/before first improvement (left) and the relative reduction for the inner and outer neutron flux profile (right)**

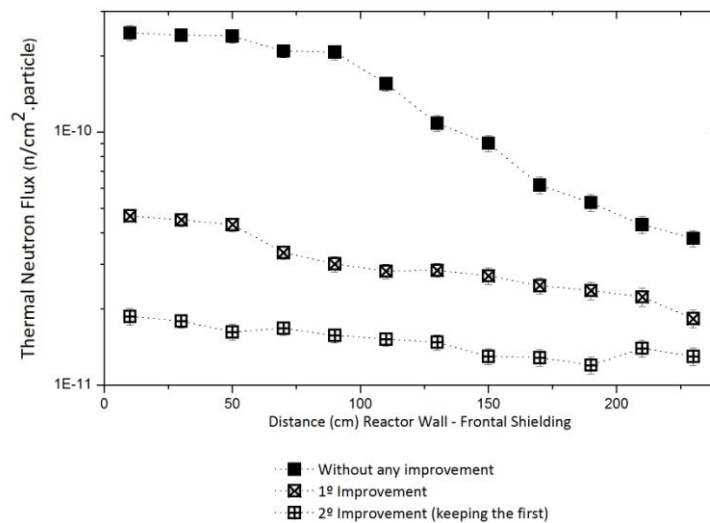
Analyzing these results from inside and outside the biological shielding it is correct to affirm that neutrons with energies above 0.5 eV emerges as thermal neutrons outside the biological shielding and these neutrons causes the interference in the other research group experiment. The second improvement should reinforce this inner-reduction of high energy neutrons so that the outer thermal neutron flux continues to reduce.

Keeping the first improvement on the modeling, the second improvement was added together and the new neutron flux inside the biological shielding and the new relative reduction are shown in figure 11.



**Figure 11 – Neutron flux profile along the inner surface of the biological shielding wall with second and first improvement added (a) and the relative reduction achieved (b).**

The second improvement reduces the neutron flux above 0.5 eV majorly at the distance interval of 0 to 30 (in figure 12 (b) it can be observed), this is the tunnel effect because it ends nearby 35 cm from the reactor wall. This tunnel was not made longer and thicker because it would compromise the BNCT facility operation preventing the claw-guided trail to delivery/withdraw samples from outside the biological shielding when the reactor is on. However only this 30 cm shielding tunnel shows some effect on the thermal neutron flux outside the BNCT biological shielding; figure 12 shows these results.

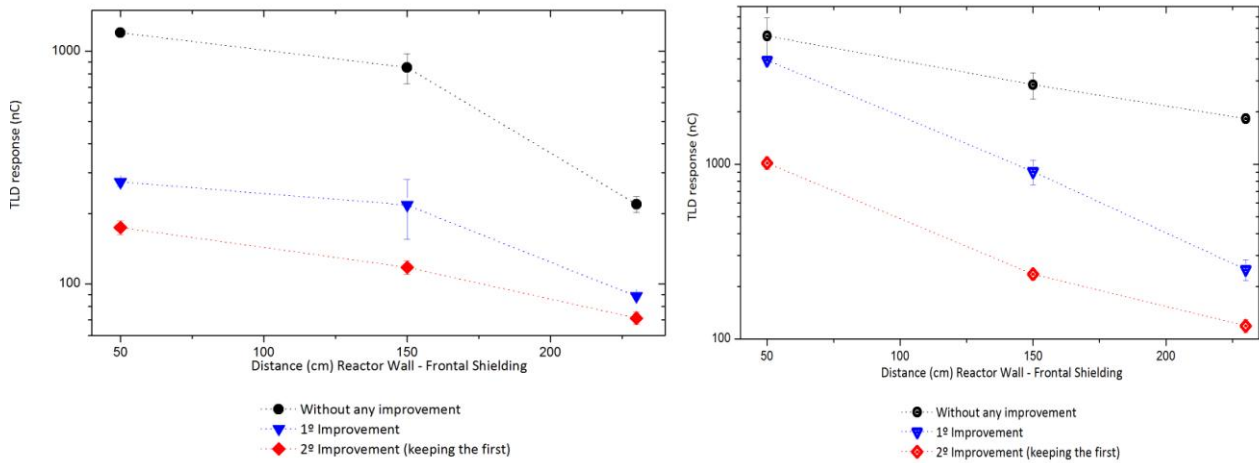


**Figure 12 – Thermal neutron flux profile along the outer surface of the biological shielding with second and first improvement added.**

The second improvement effect in the thermal neutron flux outside the biological shielding is much more evident for these firsts centimeters interval because it is in this region that the tunnel is inside the biological shielding, however the reduction also happens for the rest of the distance but less significantly.

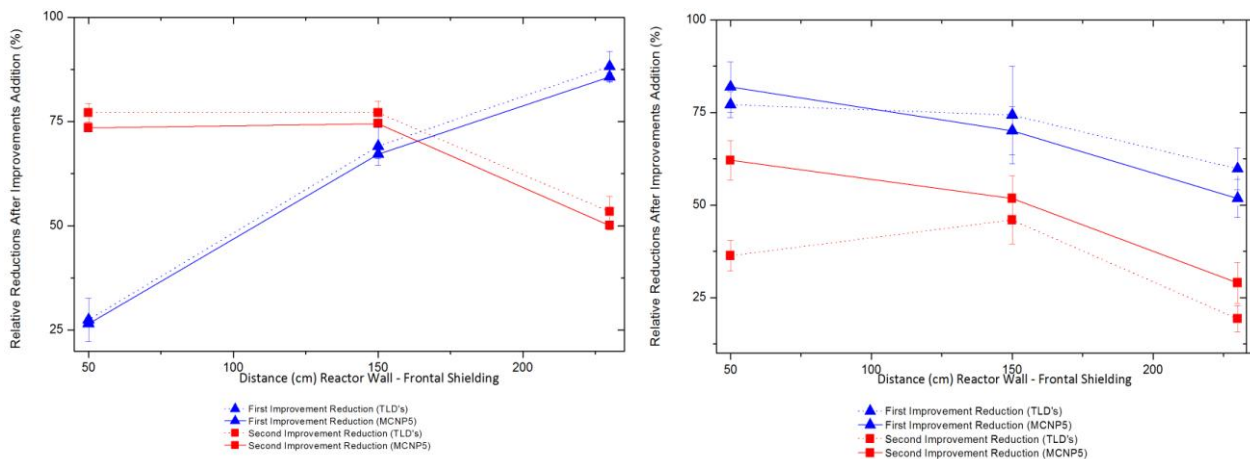
Experimental sets involving TLD's and activation detectors were performed along the BNCT biological shielding, as it can be seen in figure 6 these points are inside and outside the

biological shielding wall. That is in front the detector of the other research group, and is the same region used to acquire data from MCNP5. Figure 13 shows these results for the two improvements added to the BNCT biological shielding for the outer and inner side of the biological shielding.



**Figure 13 – TLD’s response outside the biological shielding (a) and inside (b) for the three points (see figure 7) for each improvement addition.**

The use of TLD’s to perform dosimetry in mixed neutron/gamma fields is still in study by the scientific community, in this work it is used the pair TLD 600 and TLD 700 to make this dosimetry, however this procedure is in an initial step and the BNCT research group has been studying this kind of dosimetry with TLD’s to better understand it. Figure 14 presents a combined analysis for these relative reductions with the experimental data acquired with TLD’s and the results from MCNP5, both for the inside and outside of the BNCT biological shielding.



**Figure 14 – Relative reductions (MCNP5 and TLD’s) inside (left) and outside (right) of the BNCT biological shielding**

These relative reduction shows that the methodology presented in this work after an improvement added to MCNP5 geometric modeling is useful to understand the improvements effect at the thermal neutron background field. Although, this methodology is useful only for

relative comparisons, the results from the pair TLD 600 and TLD 700 (commonly used for thermal neutron dosimetry)<sup>7</sup> shows that it can be used to further improve the BNCT biological shielding.

### 3. CONCLUSIONS

Both improvements added to the biological shielding reduces the thermal neutron flux outside the biological shielding significantly and these simulations performed with MCNP5 were helpful to understand how the neutron spectrum changes along different parts of the biological shielding. Although, the neutron source utilized does not represent a real situation due to several reactor parameters that were not taken into account, the present methodology serves to compare results and improvements effects in the thermal neutron field that leaks from the BNCT biological facility and increases the thermal neutron background.

However, only these improvements cannot ensure that this background variation will not be an inconvenient anymore. In this way, more improvements to the biological shielding are being planned involving borated polyethylene and flexible neutron shielding materials.

### ACKNOWLEDGMENTS

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