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

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ABSTRACT

The biological shielding of the BNCT (Boron Neutron Capture Therapy) research facility was constructed with the main objective of qualifying for the radio-protection rules so that the facility could be safe in terms of dose rates, even when samples are being inserted/removed from the sample position with the reactor at full power. For those purpose the shielding is useful but when the internal lead shielding is removed to insert/remove samples, a thermal neutron background variation is observed at a nearby experiment and that variation reflects on their results. The purpose of this work is to reduce such interference and their variations. Some improvements were done at the facility and a interference decrease was observed and a set of simulations are being carried out and some initial results are being obtained.

1. INTRODUCTION

The IEA-R1 research reactor is an old pool type nuclear reactor constructed at IPEN-SP in the 60's and since then it has been used for neutron experiments, material testing and for the producing of radioactive nuclides for medicine purposes. A BNCT research facility was developed at beam hole nº3 and its use is intending not only to perform BNCT experiments but also to other fields of research, such as medical physics and biology.

The BCNT research facility shielding was finished in 2003 and since then several experiments took place without any problems with the shielding, it is safe to be outside the facility when samples are being inserted/removed even with the strong neutron and gamma field inside derived from the reactor's core. Later, a nearby experiment started which was affected by thermal neutrons background variation when samples are inserted/removed at the BNCT research facility. The two facilities can not operate simultaneously in the experimental room of the IEA-R1 research reactor.

The main objective of this work is showing what kind of improvements are being done to the shielding in order to reduce these background levels as lower as it could be reached.

2. SHIELDING IMPROVEMENTS

2.1. Shielding Description

The main purpose of the shielding design[1] was to reach a high attenuation factor to attend the radiological protection rules[2] and it could not spend more than the planned budget. These two factor lead to the use of paraffin boxes and concrete blocks with respective masses of 25 kg and 34 kg each. A beam catcher is also used to reinforce the shielding, it comprises in a box of leaded walls with borated paraffin inside. The schematic view of the facility is shown in the figure 1.

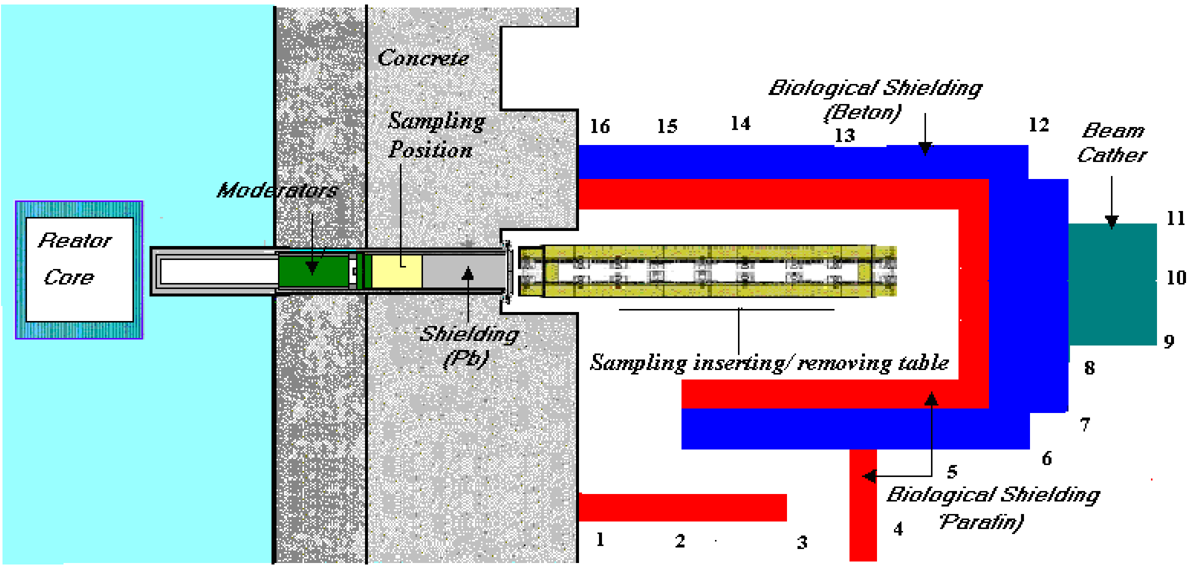


Figure 1: Schematic view of the facility constructed at BH#3 of IEA-R1 Reactor in IPEN

The biological shielding consists of a set of walls and roof made from paraffin boxes and concrete blocks with the 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). The gamma ray, neutron and gamma-neutron attenuation factor for the front wall is respectively: 15300, 600 and 3000; for the roof and the remaining walls are: 5100, 350 and 1600 [1]. The obtained dose levels around the facility attending the radiological protection rules. The sum of the all facility's shielding materials is about 35 t and that number gives the idea of the strong neutron-gamma field inside of the facility when changing sample with the reactor at full power.

To change samples, the sample position and internal shielding tube are moved over the sampling inserting/removing table and the neutron-gamma field increase outside the biological shielding.

Figure 2 presents the schematic view of all the beam holes of the IEA-R1 nuclear reactor; as can be seen in this figure, the position of the nearby experimental facility in beam hole #5 is near to the BNCT research facility.

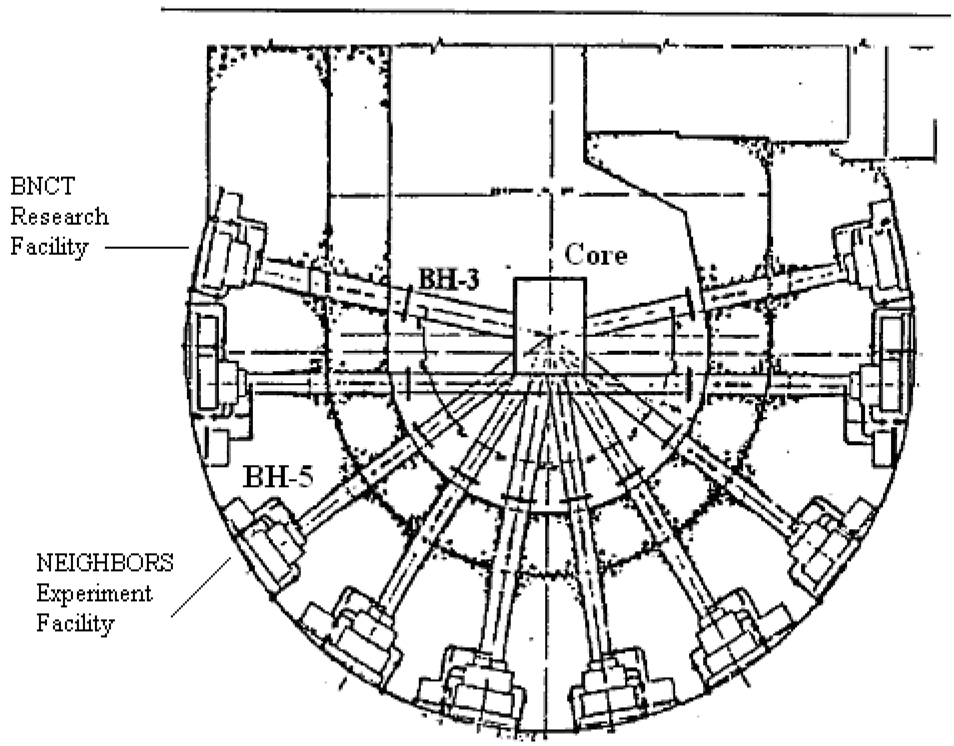


Figure 2: Schematic view of all the IEA-R1 beam holes

The first step taken to add improvements to the shielding was marking several points along the shielding to assist the data acquisition and after all the improvements done some points around the neighbor's experiment equipments were marked to certificate the improvements results as near as possible the neighbor's experiment. The facility's shielding points are shown in figure 1.

2.2. Improvements Characteristics

A major concern when introducing improvements is to maintain those dose levels around the facility attending the radiological protection rules; according to this, the first improvement done were a set of lead blocks covered with a cadmium foil (1mm thickness) put in the window of the beam hole. All the improvements done so far must be easy to displace and place along the shielding and for that reason duck tapes were used to fix some improvements, as those improvements are not final and all the process has not finished yet, no final structure was done to fix those improvements. The first before/after situation is shown in figure 3.

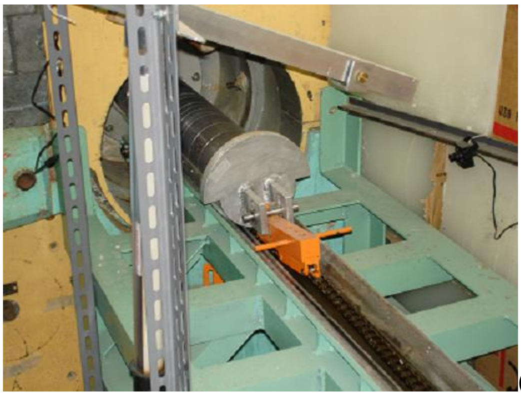
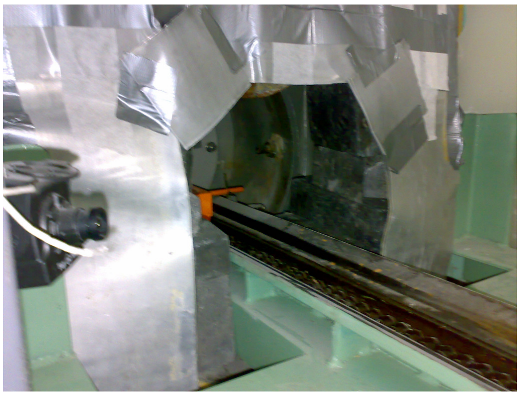

(a)

(b)

Figure 3: Photos before (a) and after (b) the first improvement made

The reason of this first improvement was to reduce the thermal neutron field as close the beam hole as possible. The cadmium was used because it has an excellent cross-section for thermal neutron absorption, the reason of a set of lead blocks after the cadmium foil is to attenuate the gamma field inside the facility and produce some backscattering with thermal neutrons derived from the reactor's core.
After this first improvement, a set of boxes with borated paraffin (5%) covered with cadmium (1 mm thickness) was arranged along the table with the guide rail that brings in/out the sample position in a way that a tunnel could enclose the sample basket when samples are being removed/inserted at the facility. Figure 4 shows the before and after comparison for this improvement.

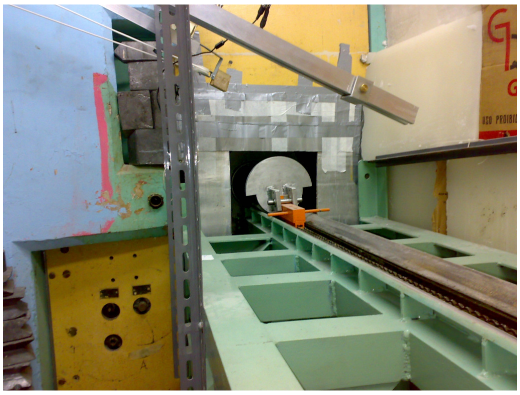
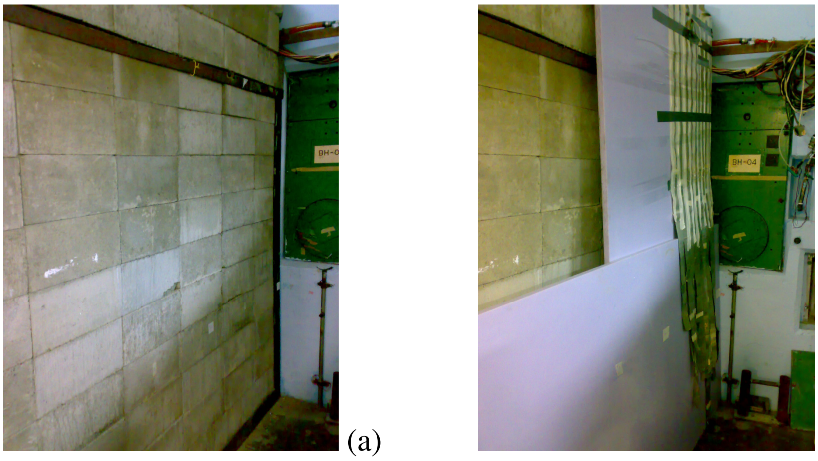

(a)
(b)


Figure 4: Photos before (a) and after (b) the second improvement made

The third and last improvement was arranged outside the shielding facility in front of the neighbor's experiments (near points 14, 15 and 16 of figure 1); a set of borated polyethylene cover with cadmium was arranged. The use of borated polyethylene was to slow down fast neutrons up to the thermal energy and to reduce these thermal neutrons with the high absorption cross section of the boron -10 (~ 5% in the material) and the coverage of cadmium is to annihilate thermal neutrons. Figure 5 shows the after and before comparison for this last improvement.



(a) (b)

Figure 5: Photos before (a) and after (b) the last improvement made

All the improvements made so far have as main objective to keep the dose levels attending the radiological protection rules, reducing as possible as the thermal neutron dose level around the facility and near the neighbor's experiment without increasing the gamma dose level after all the shielding improvements.

2.3. Results

The spectra of neutron-gamma field that leaves the beam hole is unnecessary at this first stage of this work, because all the improvements done is to try to annihilate the thermal neutron leakage that interferes in the neighbors experiment, so that the others users of the BNCT research group could work without restriction as soon as possible. After each added improvement in the facility's shielding, background levels were obtained with the support of the IEA-R1 nuclear reactor radioprotection staff. The radioprotection equipment used was the IdentiFINDER[3] from Thermo Scientific Company, this equipment shows the counts per second for thermal neutrons and it also shows the dose levels for gamma radiation. The IdentiFINDER has a high efficiency ^{3}He gas tube thermal neutron detector[4] and along with the quick response and its easiness use it is a good choice for this work step.

After any improvement implanted the counting was obtained with the beam hole closed (Cc), then, the beam hole were opened and a second counting were obtained (Co). The method to analyze if the improvement was successful was to divide the counts with the beam hole opened per the counts with the beam hole closed (Co/Cc). The closest to 1 is this ratio, better is the result, because it means that it is closest to the non interference situation. The table 1 shows these ratios for all the most important points around the facility's shielding; these are the important points because it is in the shielding side in front of the nearby experiment.

Table 1: Neutrons ratios Co/Cc for the three last shielding points

Shielding Points	16	15	14
	Co/Cc	Co/Cc	Co/Cc
Without Any Improvement	4.00 ± 0.60	5.48 ± 0.82	6.67 ± 1.00
After First Improvement	2.70 ± 0.40	1.50 ± 0.22	2.00 ± 0.30
After Second Improvement	2.55 ± 0.38	1.30 ± 0.19	1.47 ± 0.22
After Last Improvement	1.21 ± 0.18	1.30 ± 0.19	1.25 ± 0.18

It can be seen that those c.p.s have been reduced significantly in this three major points around the shielding; it also can be seen that the best reduction took place after the first improvement, because it is at the edge of the beam hole, so, the probability of scattered neutrons is reduced and the probability of neutron absorption is increased.

After the second improvement, the reduction was soft for the three points, because the improvement was away from the beam hole exit. After the third improvement those reductions continued to be soft for the points 15 and 14, but for the point 16 the reduction was much more significant. That can be explained by the fact that the last improvement is much more concentrated near the junction of the biological shielding with the Reactor pool wall where there are beam streaming and that reflects obviously in the counts at the point 16. This fact can be seen in figure 5b, the amount of borated polyethylene and cadmium is higher next to this junction. Also is evident that without any improvement the ratio Co/Cc is higher as it is farther from the beam hole exit; this happens because the scattered neutron field gets bigger as it moves far from the beam hole exit. But that does not mean the counts per second in these points are higher than the point 16, per example. After all improvements done, four points around the nearby experiment equipment were marked for a final verification. These four points were marked in a way to cover all the nearby equipment, the schematic view of these points around the equipment is presented in the fig. 6.

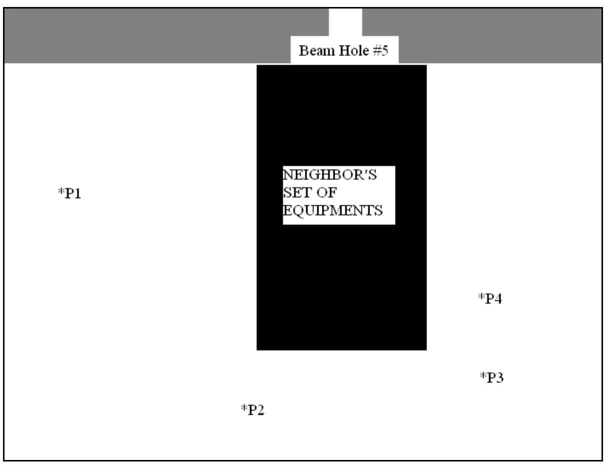


Figure 6: Schematic view of the four points around the nearby equipment

Using the same methodology of analysis the ratio between the counts rate with the beam hole opened and the counts rate with the beam hole closed were made to certificate those reductions seen in table 1. This was done only for the final improvement because it is the current situation. The table 2 presents the results of Co/Cc for the four points marked around the neighbor's equipment.

Table 2: Ratio Co/Cc for the four points marked around the nearby equipment

Points	P1	P2	P3	P4
	Co/Cc	Co/Cc	Co/Cc	Co/Cc
Current Situation	1.39 ± 0.20	1.57 ± 0.23	1.36 ± 0.20	1.11 ± 0.16

In all these four points presented in table 2 the ratio Co/Cc appears approximately in the same order of the BNCT facility's shielding reasons but with the main difference that the highest c.p.s with the beam hole opened (Co) acquired in these four points (table 2) was smaller than 14. So, it is reasonable to affirm that these improvements done in the BNCT facility's shielding had a positive effect over the c.p.s around the neighbor's experiment equipment.
A set of simulations using the transport code DOT 3.5[5] and MCNP-4C[6] are being carried out to guide future shielding improvements at the facility.

3. CONCLUSIONS

After these sets of improvements the counts per second has been reduced significantly around the shielding points and around the neighbor's equipment points. And the gamma field did not increase significantly before any improvement, keeping the facility under the radioprotection rules. The results presented in this work show that the path taken to implant improvements to the facility's shielding are in the right way. Future works with thermo luminescent dosimeters TLD[7] and activation foil detectors are scheduled to improve these results and also a complete shielding simulation using the transport code MCNP-4C.

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