

Neutron Flux and Gama Dose Profile Measurements and Calculations Along a Phantom in the BNCT Facility of IEA-R1 Reactor

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Abstract

A BNCT (Boron Neutron Capture Therapy) facility has been built at IEA-R1 reactor. The on going BNCT experiments demand the maximization of the thermal neutron component of the irradiation field and the minimization of its epithermal and fast neutron components together with the reduction of the gamma contamination. This work was developed with the objective of evaluating whether the present radiation field in the facility is suitable for carrying on BNCT studies and to establish a work methodology with phantoms in this facility. In order to achieve these objectives, thermal and epithermal neutron flux measurements, in the sample irradiation position were performed using hyper-pure Gold activation detectors and applying the Cadmium ratio. Absorbed dose due to gamma radiation was determined by TLD 400. A cylindrical phantom composed by acrylic discs was designed, built and tested in the facility. DOT 3.5 computational code was used to retrieve neutron fluxes and the gamma dose estimates along the phantom. Although some improvements still need to be made in the methodology under implementation, computer simulations carried out with DOT code presented a good agreement with experimental data for most part of the evaluated profile. In the position corresponding to about half the length of the phantom, the following experimental values were obtained: thermal neutron flux $(2.52 \pm 0.06) \cdot 10^8 \text{ n.cm}^{-2} \cdot \text{s}^{-1}$, epithermal neutron flux $(6.2 \pm 0.3) \cdot 10^6 \text{ n.cm}^{-2} \cdot \text{s}^{-1}$, absorbed dose due to thermal neutrons $(4.2 \pm 1.8) \text{ Gy}$ and $(10.1 \pm 1.3) \text{ Gy}$ due to gamma radiation. The obtained values show that the fluxes of thermal and epithermal neutrons flux are appropriate for studies in BNCT, however, dose due to gamma radiation is high, indicating that the facility should be improved.

Keywords: BNCT, phantom, activation detector, TLD 400.

1. Introduction

The reactor IEA-R1 is a pool type multi-purpose nuclear research reactor. Its first criticality occurred in 1957 and set the origin of Energy and Nuclear Research Institute (IPEN). Since then it has been submitted to many improvements such as the upgrade from 2MW to 5MW that was carried out in late nineties. Although NCT has not stood as one of the application in its design, an irradiation facility has been designed and built (figure 1) at IEA-R1 to perform BNCT studies (Coelho et al., 2002).

As the irradiation sample position stands inside one of the reactors beam hole, only Radiation Physics and Radiobiology experiments are adequate to be

carried out in this facility, i.e. no human treatment shall be conducted.

Thermal component maximization of the neutron radiation field is demanded by experiments under conduction. Minimization of its epithermal and fast components and the gamma contamination are also sought.

A phantom was designed and built in order to evaluate the radiation field in the sample irradiation position and its dose distribution. Activation detectors and thermoluminescent dosimeters were used to perform this task.

This work presents calculated and experimental results for thermal and epithermal neutron fluxes and gamma dose profiles along the phantom.

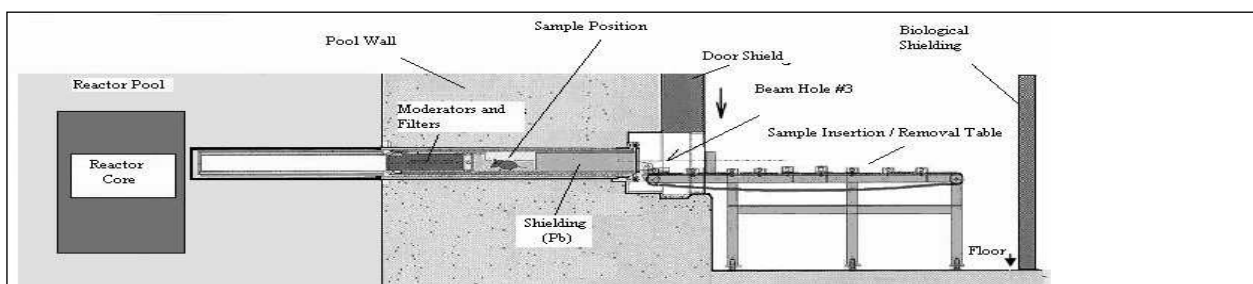


Figure 1. Schematic view of the BNCT facility at the IEA-R1.

2. Materials and Methods

In order to perform intended experiments and to attend the facility working conditions (sampling remote handling and an irradiation position in a retractable module) a phantom was designed and constructed. It consists of a 22 cm long by 10 cm outer and a 9.1cm inner diameter acrylic cylinder shell (figure 2). The cylinder is filled with a set of acrylic discs – 3 mm thick each (figure 3). The assessment of the measured radiation field and dose parameters were done by detectors and dosimeters placed between the disks.

Neutron flux measurements were carried out by hyper-pure gold activation detectors. The assessment of neutron field thermal and epithermal components were done by the Cadmium ratio (Bitelli, 1988).

Commercial thermoluminescent dosimeters - TLD 400 - from Thermo Scientific were used for gamma dose profile measurements. TLD 400 is a Calcium Fluoride dosimeter doped with Manganese (CaF₂:Mn). It is used to determine the absorbed dose due to gamma radiation and presents a linear response as a function of the absorbed dose up to 100 Gy (Kafadar et al., 2009).

The TLDs 400 were selected and calibrated by using a panoramic type cobalt-60 source (Carneiro, 2008).

A set of calculations were also carried out so to stand as a supporting data in the appraisal of the experimental results. The Two Dimensional Discrete Ordinates Radiation Transport Code, DOT 3.5, was used to simulate the phantom in the sample irradiation position. The computational program ISODOSE, developed by the Center of Nuclear Engineering (CEN) of IPEN, was used to convert the neutron fluxes estimates retrieved by DOT 3.5 to absorbed dose (Silva, 2002).



Figure 2. Acrylic cylinder of the phantom.

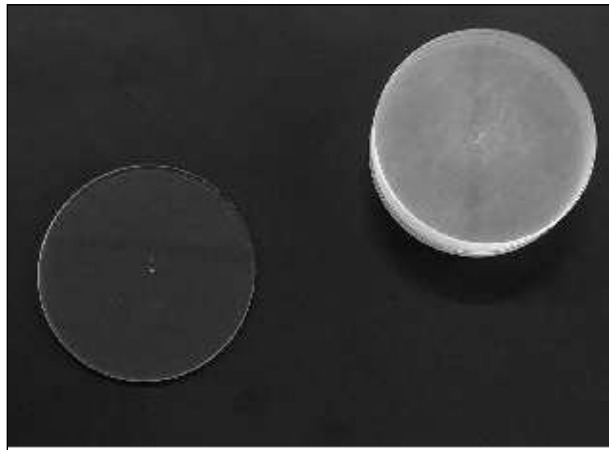


Figure 3. Acrylic discs that fill the phantom.

3. Results and Discussions

The phantom was filled with 20 discs corresponding to 60mm of acrylic; and activation detectors and the TLDs were set in the following positions: 0 (on the outer surface of the first disc, i.e. before the phantom downstream radiation field), 6, 12, 18, 24, 30, 36, 42 and 48 millimeters. Each position held pairs of Gold activation foils with and without cadmium cover and TLDs 400; the irradiations lasted 30 minutes. In order to build the thermal and epithermal neutron fluxes and gamma dose profiles, 3 distinct irradiations were performed. Each irradiation retrieved results from 3 different positions along the phantom placed 18 cm apart one from another. Reactor operation power was the same for all irradiations (3.5 MW).

The measured and simulated results for thermal neutron flux are show in figure 4.

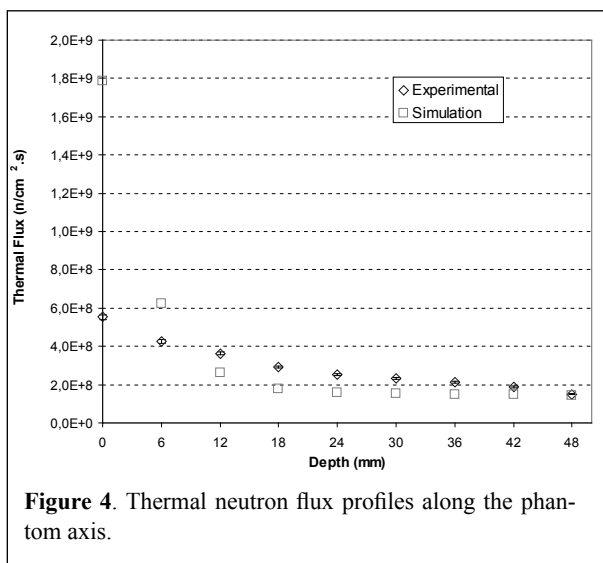


Figure 4. Thermal neutron flux profiles along the phantom axis.

Figures 5 and 6 show, in different scale span, the epithermal neutron flux profiles assessed both by measurements and by calculations.

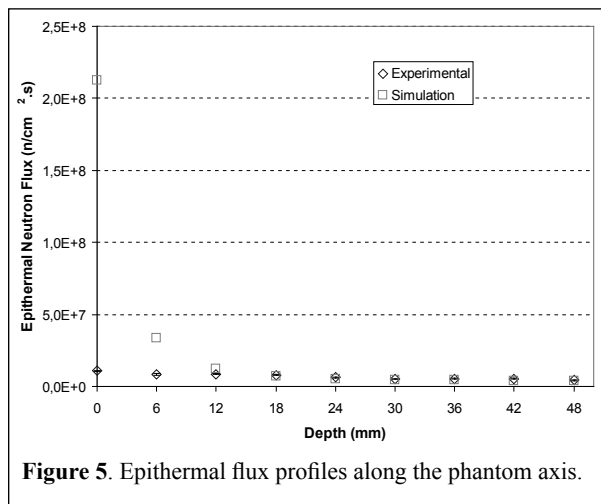


Figure 5. Epithermal flux profiles along the phantom axis.

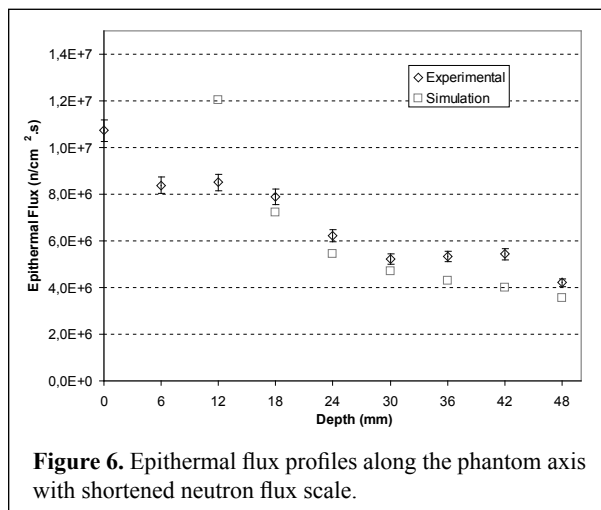


Figure 6. Epithermal flux profiles along the phantom axis with shortened neutron flux scale.

The largest difference between the measured and simulated values lies in the first position for both neutron fluxes. The first point of these profiles stands right on the interface between the 2 media - air and acrylic phantom. As this disagreement, in a smaller scale, still extends into the phantom, efforts have been done in order to cope with it. However a much better agreement between experimental and calculated results is found for the other points, with even an overlap of values.

The absorbed gamma dose along the phantom is shown in figure 7. This figure shows a pattern which suggests a coupling among the experimental results of each individual irradiation conducted to build the gamma dose profile. Besides, as in the case for neutron fluxes, experimental results for the first points stand far apart from the calculated ones. However, a better accordance is found for the last 2/3 of the obtained profiles.

In the position corresponding to about half the length of built profile, the following values were experimentally obtained: thermal neutron flux $(2.52 \pm 0.06) \cdot 10^8 \text{ n.cm}^{-2} \cdot \text{s}^{-1}$, epithermal neutron flux $(6.2 \pm 0.3) \cdot 10^6 \text{ n.cm}^{-2} \cdot \text{s}^{-1}$, absorbed dose due to thermal neutrons $(4.2 \pm 1.8) \text{ Gy}$ and $(10.1 \pm 1.3) \text{ Gy}$ due to gamma radiation.

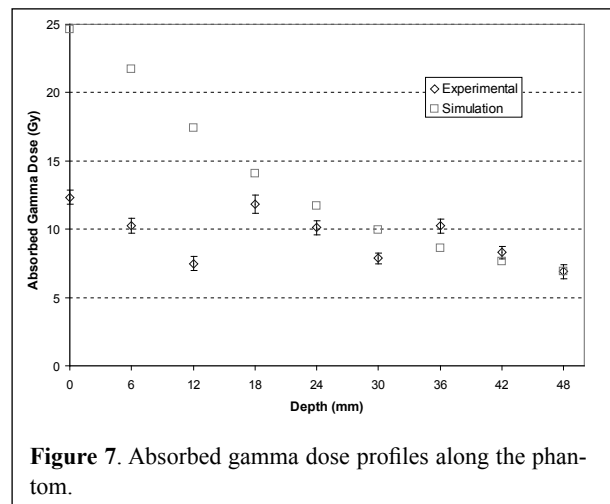


Figure 7. Absorbed gamma dose profiles along the phantom.

Computer simulations carried out with DOT code presented a good agreement with experimental data from 18 mm depth and beyond.

4. Conclusions

The obtained values show that the thermal and epithermal neutrons fluxes are appropriate for conducting studies in BNCT. However, dose due to gamma radiation is still too high, and therefore, improvements in the facility should be provided to cope with this hurdle.

Experimental and calculated results show a good accordance for the last 2/3 of the phantom depth profile. However a great disagreement is verified for the shallower points of this profile, pointing out that improvements must be made in methodology under implementation. Experimental results show, however, that a great effort must be taken to deepen the evaluation and comprehension of the parameters which affect the irradiation field and the detector responses. This is mainly true for TLDs.

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5. References

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