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Experimental Results Analysis and Simulation to Evaluate Flux and Dose at the Irradiation Sample Position of the BNCT Research Facility

Rafael O. R. Muniz, Paulo R. P. Coelho e Graciete S. Andrade e Silva

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
romuniz@ipen.br, prcoelho@ipen.br, gsasilva@ipen.br

ABSTRACT

To study the BNCT (Boron Neutron Capture Therapy) researchers of the IPEN developed and constructed a facility in the IEA-R1 reactor from IPEN/CNEN-SP, using the beam hole number 3. This facility was constructed to perform experiments of radiation field characterization (neutrons and gammas) suitable to the application of the BNCT technique along with other kinds of experiments in several fields of physics and biology.
The purpose of this work is to analyze experimental results, and the simulation to evaluate neutron flux and dose due to gamma radiation at the sample irradiation position of the facility.
For the thermal and epithermal flux measurements, the cadmium rate technique with activation foil detector was used, and for the dose determination due to gamma radiation, thermo luminescent dosimeters were used. In the simulation part of this work, the computational transport code DOT 3.5 was utilized.
With activation foil detector, a thermal neutron flux of $2.31.10^8 \pm 0.03.10^8$ n/cm^{2}s, and for epithermal neutrons of $4.6.10^6 \pm 0.1.10^6$ n/cm^{2}s were observed at the facility sample irradiation position.
With thermoluminescent dosimeters, a dose rate for gamma radiation of 21 ± 1 Gy/h was observed at the sample irradiation position.
The observed simulation results show agreement with those experimental flux measurements.

1. INTRODUCTION

Cancer is a disease that affects millions of people all over the world. Researches for cancer treatments have been developed in several ways to preserve healthy cells and to, potentially, kill cancer cells. Treatments are applied separately or as combined techniques, depending on the stage of the cancer and the affected organ. The most known treatments are: surgery, radiotherapy and chemotherapy.

The Neutron Capture Therapy (BNCT) is a treatment intended to apply, at the maximum, the idea of selecting cancer cells, destroying them and preserving the healthy cells. This therapy consists in injecting a compound that contains boron-10 that is preferentially absorbed by cancer cells. After that, the body region containing the tumor is exposed to a thermal neutron beam (neutrons with energy lower than 0.5 eV). Boron-10 has a high cross section for thermal neutron absorption, and, as consequence, a nuclear reaction yields an alpha particle and Lithium-7 [1]. Those particles have a high linear energy transfer (LET). That means that they deposit a huge amount of energy in a small distance, and this distance is in the order of cancer cells which leads to the cell death.

As the compound is preferentially absorbed by cancer cells, selectivity between healthy cells and cancer cells is reached. Due to this selectivity, this treatment is applied in cases that conventional treatments cannot be applied, or have its potentiality reduced due to damages it causes to healthy cells. The brain tumor (glioblastoma multiforme) is an example of that. To study BNCT treatment, researchers of the Nuclear Engineering Center (CEN) projected and constructed a facility in the IPEN/CNEN-SP IEA-R1 reactor [2], using beam hole number 3 (BH#3). Fig. 1 shows a schematic view of this experimental facility.

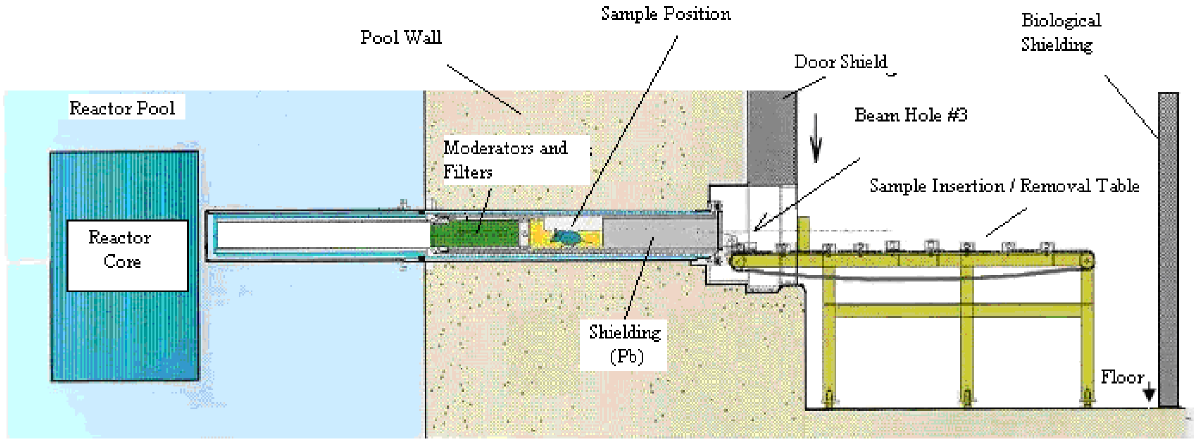
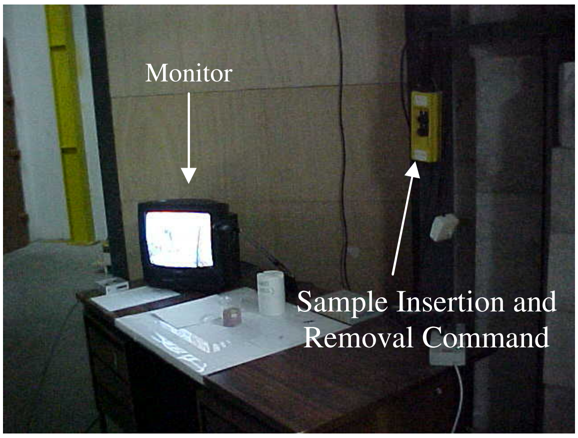


Figure 1. Schematic view of the BNCT research facility at IEA-R1.

Neutrons arising from the reactor core and entering into the BH#3 pass through filters and moderators assemble to improve their energy spectrum and minimize the gamma rays component in the sample irradiation position. Outside the BH-3 was constructed a biological shield to allow insertion and removal of samples with the reactor in full power attending radiological protection rules in the reactor experimental hall. To change the samples a system out of the facility move the sample position and the BH#3 internal lead shielding (Fig.1) over the sample inserting/removing table; then a claw lowers the samples using a trail and puts them in the irradiation position (Fig. 2).



(a)

(b)

Figure 2. a) System to remove/insert samples and to monitor. (b) Claw with the sample going down through the trail.

This paper aims to present the initial experimental and simulated results of the thermal and epithermal neutrons flux and the absorbed dose due to gamma radiation in the sample irradiation position.

2. EXPERIMENTAL METHODOLOGY

At the sample irradiation position there is a mixed neutron and gamma rays field and is required to determine these two components to characterize it and evaluate if it is appropriate for BNCT researches. Activation foils were used to measure the neutron flux. For the gamma radiation was used thermoluminescent dosimeters.

2.1. Activation Detectors

This work high purity activation foils detectors were used. The neutrons flux measures for activation are made by counting the induced radioactivity on the detectors, using a gamma ray spectrometry system. This technique is well established in the literature.

The classification of neutrons in thermal, epithermal or fast is based on their kinetic energy and their intervals of energy in each region depend on the technique used. The classification used in this study for each region is: thermal up to 0.5 eV, epithermal between 0.5 eV and 10 keV and fast over 10 keV. To determine the thermal and epithermal flux was used the technique of cadmium ratio [3] which is to radiate in the same conditions a foil of gold covered with cadmium and other without the coverage of cadmium. Cadmium acts as a filter absorbing the neutrons up to 0.5 eV, then the foil of gold with coverage of cadmium will only responds to epithermal neutrons; by the ratio of these two foils can be obtained the thermal and epithermal flux.

2.2. Thermoluminescent Dosimeters

Thermoluminescent dosimeters of calcium fluoride (CaF2: Mn), TLD 400 as identified by the manufacturer Thermo Scientific, were used to determine the absorbed dose due to gamma radiation. These TLDs have a used range from 0.1 μGy to 100 Gy.

Before using thermoluminescent dosimeters two important steps are needed to obtain the absorbed dose: selecting the chips and calibrating them. The selecting serves to separate the chips with the same sensitivity and reproducibility [4] and the calibration aims to convert the response [5] of the dosimeter to absorbed dose. The magnitude of the measure of the TLD reader is the electric response (nC) generated in the TLD's reader due to the light emitted by the dosimeter. The panoramic source of ^{60}Co (Fig. 3) of the Technology Center of Irradiation (CTR) of IPEN was used to obtain the TLD 400 calibration curve for gamma radiation. This source is screened by the International Atomic Energy Agency (IAEA) through the program IDAS (International Dose Assurance Service) with a uncertainty of 1.7% in the dose value.

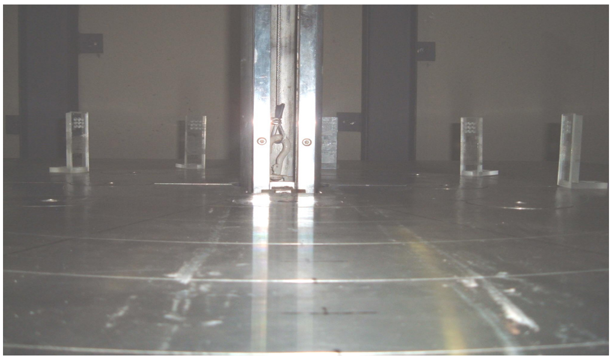


Figure 3. ^{60}Co panoramic source of CTR.

3. COMPUTATIONAL SIMULATION

The two dimensional Discrete Ordinates Transport code, DOT 3.5 [6], have been used to simulate the experimental facility in R-Z geometry with cylindrical symmetry about the beam hole axis.

The transport calculations was performed using a structure with 89 radial and 221 axial mesh, 22 neutron energy groups and 18 gamma ray energy groups and S100 forward biased angular quadrature [7]. The energy source for each group was proportional to power density weighted with the spectrum of energy and the computational program ISODOSE was used to convert the results from DOT neutron and gamma ray fluxes to dose.

4. RESULTS

The TLD 400 calibration was performed using 10 points of doses from 5 to 80 Gy, as shown in Fig. 4 with its standard deviation, where each point is the mean of nine TLD 400 responses. The dose uncertainty is of 1.7% coming from the source calibration IDAS program.

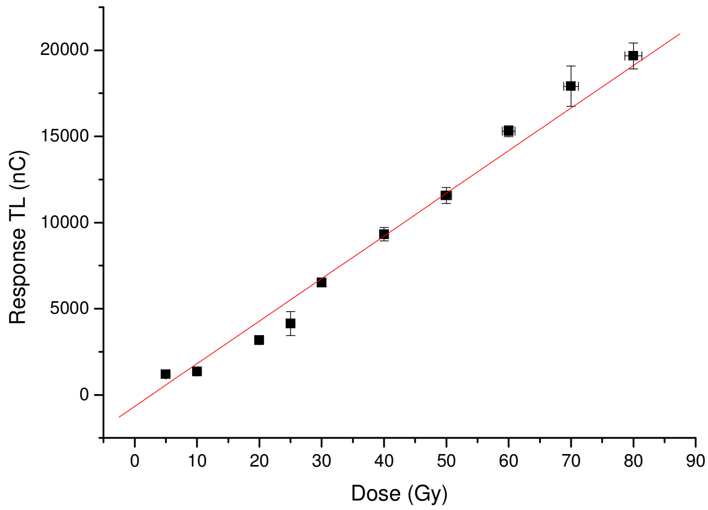


Figure 4. TLD 400 calibration curve.

Using the linear fit [8] the TLD 400 irradiated response was converted into absorbed dose. This absorbed dose value is presented in table 1, together with the value obtained by simulation.

Table 1. TLD 400 irradiated at the sample position at the facility

Experimental Values					Simulated Values
Irradiation Time (min)	Dose (Gy)	Dose Uncertainty (Gy)	Dose Rate (Gy/h)	Dose Rate Uncertainty (Gy)	Dose Rate (Gy/h)
45	15.8	0.8	21	1	40

Currently we are studying if the difference between the simulated and measured results is due to the energy calibration of TLD 400. There is a significant variation due to differences in energy between the calibration and irradiation. The energy spectrum of gamma radiation simulated with the DOT has an average energy of 626 keV and the calibration curve was constructed with the ^{60}Co source, which emits two photons, one with energy of 1173.237 keV and other 1332.501 keV.

The experimental values and those simulated with the DOT 3.5 for the thermal and epithermal neutrons flux are presented in table 2.

Table 2. Thermal and epithermal flux

Experimental Values				Simulated Values	
Themal Flux (n/cm^2s)	Thermal Flux Uncertainty (n/cm^2s)	Epithermal Flux (n/cm^2s)	Epithermal Flux Uncertainty (n/cm^2s)	Thermal Flux (n/cm^2s)	Epithermal Flux (n/cm^2s)
$2.31.10^8$	$0.03.10^8$	$4.6.10^6$	$0.1.10^6$	$9.5.10^8$	$1.14.10^8$

4. CONCLUSIONS

Preliminary values were determined for the thermal and epithermal neutrons flux and the absorbed dose due to gamma radiation, in the sample position. The comparison between simulated and experimental values is satisfactory at this stage of work. As a continuation of this project we are working to improve the experimental and simulation results to obtain a good convergence between the simulated and experimental values.

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