CHARACTERIZATION OF THE BNCT EPITHERMAL COLUMN OF THE FAST REACTOR TAPIRO (ENEA) AND DOSE MEASUREMENTS IN PHANTOM UTILISING NOT-CONVENTIONAL DETECTION

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The epithermal column of TAPIRO reactor has been characterized and in-phantom dose has been imaged, with the purpose of determining parameters and data whose knowledge will be of main importance for future experimentation regarding boron neutron capture therapy (BNCT). In-phantom measurements have been carried out mainly utilizing a recently developed method for absorbed dose imaging, based on gel-dosimeters. Gel-dosimeters have revealed to give significant support to thermal or epithermal neutron dosimetry: in fact, the modality of energy release in gel-dosimeters is very similar to that in tissue, and with proper adjustment of the isotopic composition of gel matrix, the various dose components are separated.

1 Introduction

The continuous improvement in the field of radiotherapy has resulted in change of irradiation modalities aimed at obtaining high ratio of tumor to normal-tissue dose. Moreover, radiation fields having high linear energy transfer (LET) and high relative biological effectiveness (RBE) are preferred. Boron neutron capture therapy (BNCT) is a particular kind of radiotherapy, involving conformal modality and high LET radiation. In this therapy, the high cross section (σ = 3837 b) of ^{10}B for the reaction with thermal neutrons $^{10}B(n,\alpha)^{7}Li$, the short range in tissue of the emitted particles and their high LET and RBE are exploited for obtaining localized energy deposition and high biological effect. A suitable amount of ^{10}B is selectively accumulated in tumor tissues and then the patient is exposed to thermal neutrons, for skin tumors, or to epithermal neutrons, for deep tumors.This therapy is still in phase of experimentation, and its development involves multidisciplinary research. It is necessary to improve boron carriers, in order to achieve high ^{10}B concentration in tumor cells and low concentration in healthy tissue, to improve neutron sources, in order to achieve maximum thermal neutron fluence in the region of the tumor,

and also to improve dosimetry methods, in order to know the spatial distribution of the various dose components having different biological effect. A wide presentation of issues related to NCT is reported in a recent IAEA publication [1].

At present, the fast research reactor TAPIRO (ENEA, Casaccia, Italy) is principally dedicated to research regarding BNCT. Thermal and epithermal columns have been suitably designed and constructed [2], with the purpose of inquiring about cell survival, performing experimental treatment of small animals and developing suitable dosimetry techniques both for neutron field characterization and for in-phantom dose determination.

In this work, TAPIRO epithermal column has been characterized and a method, recently proposed, for in-phantom dose imaging, separating the various kinds of contributions of secondary radiation, has been improved.

2 Characterization of TAPIRO epithermal column

TAPIRO reactor is a highly enriched (93.5%) ^{235}Uranium fast neutron facility. The power is 5 kW and the maximum neutron flux is $4 \cdot 10^{12}$ cm^{-2} s^{-1}. Thermalizing structures can be inserted or removed, depending on experimental exigencies.

Neutron spectrometry measurements were performed in the empty main column of the TAPIRO reactor. These spectra were useful for setting the main constraints of the design of the irradiation facility for BNCT. The measurements were performed with a set of five moderation detectors (Bonner spheres).

The epithermal-column consists of a parallelepiped-shaped chamber, 40×40 cm^2, and depth 70 cm, shielded with aluminum (5 mm). The collimator has squared shape 10×10 cm^2. At maximum nominal reactor power, the epithermal flux at collimator, measured with activation technique, has resulted to be about $7.4 \cdot 10^8$ cm^{-2} s^{-1} and the thermal fluence about 10^7 cm^{-2} s^{-1}. The dose in tissue at a distance of about 1 cm from the collimator has been measured with the gel dosimeters described in next session: the experimental value of such a dose, at maximum reactor power, is $2.1 \cdot 10^{-4}$ Gy/s, well consistent with the dose at collimator calculated during column designing, that was of $2.3 \cdot 10^{-4}$ Gy/s.

A map of the γ-dose in the empty volume of the epithermal column has been performed by means of thermoluminescent dosimeters (TLD). To this purpose, TLD-300 (CaF_2:Tm) has been chosen, whose sensitivity to thermal and epithermal neutrons has shown to be negligible [3]. In the central axis of the epithermal column, the γ-dose has been measured with gel dosimeters too. The results in the central horizontal plane of the column are reported in Figure1.

To lower the γ-dose at collimator, where phantoms have being irradiated, a lead plug 10 cm thick has been placed inside collimator aperture, and the γ-dose has been measured again in the region near collimator. The results are shown in Figure 2, near the view of the epithermal column.

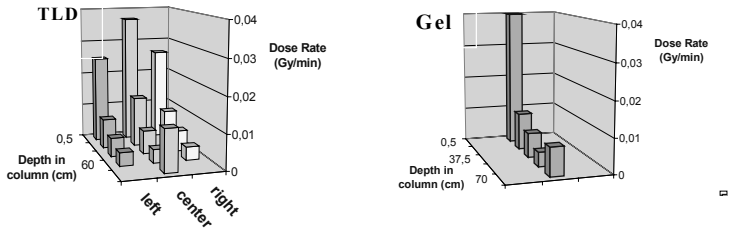

Figure 1. Gamma-dose in the horizontal central plane of the epithermal column. Depth in column is measured from the collimator

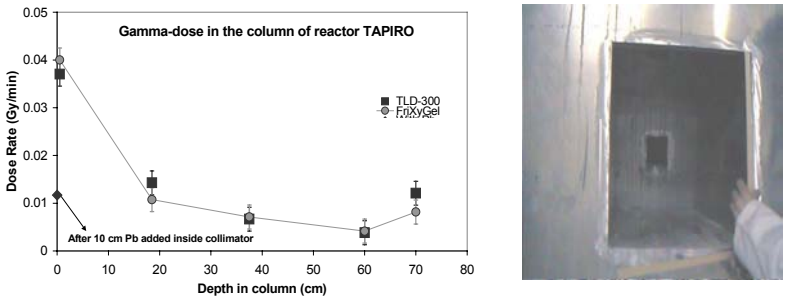

Figure 2. Experimental values of γ-dose in the central axis of TAPIRO epithermal column, vs distance from collimator, and view of the epithermal column.

3 In-phantom imaging of absorbed dose

The experimental determination of dose components in neutron fields is very complex. Besides the therapy dose due to boron reactions, it is necessary to determine the dose released by neutron reactions with tissue components. From thermal neutrons, the absorbed dose is mainly due to the reactions with H and N:

$^{1}H(n,\gamma)^{2}H$ (σ=0.33 b) and $^{14}N(n,p)^{14}C$ (σ=1.81 b).

Also the background γ-dose has to be taken into consideration. For epithermal beams, the elastic scattering with hydrogen nuclei is not negligible and recoil proton dose has to be spatially determined too. The relative dose contributions of all such dose components depend on irradiation geometry and neutron energy spectrum.

For in-phantom dosimetry, promising results have been obtained [4] with gel dosimeters consisting in tissue-equivalent (TE) gels in which a ferrous sulphate solution, which is the main component of Fricke standard dosimeter, is incorporated. Ionising radiation produces conversion of ferrous ions Fe^{++} into ferric

ions Fe^{+++}. The metal ion indicator Xylenol Orange (XO) is added to gel components, because the complex of XO with ferric ions produces optical absorbance in the field of visible light (585 nm). A method for gel-layers imaging by means of a CCD camera, equipped with an optical filter around 585 nm, has been proposed [5] and developed.

In gel dosimeters, which are in practice diluted water solutions, the action of ionising radiation is the same of that in human tissue. This is very important in neutron dosimetry. In fact, the absorbed dose, which is due to secondary radiation, is the same as in tissue provided that the isotopic composition is identical. Moreover, if a gel dosimeter is depleted (or added) of one isotope responsible for a dose component, from comparative analysis of images detected with different gels it is possible to separate such a dose contribution. This point is just the fulcrum of the proposed dosimetry approach, which is the only method for experimental imaging of absorbed dose in thermal and epithermal neutron fields, at therapy dose level, separating the various dose components.

Gel-dosimeters with different isotopic compositions have been prepared: 1) TE gel, with the proper amount of H and N; 2) Nitrogen-depleted gel; 3) gel added with ^{10}B in the amount typically employed for therapy; 4) gel with suitable amount of Gd. From the analysis of the images detected with such gels it is possible to obtain the spatial distribution of the photon dose, the dose due to protons from reactions with N, the therapy dose due to ^{10}B and the doses due to Gd. There is some interest in studying Gadolinium, because it is a contrast agent for NMRI and it can be advantageous, if bound with ^{10}B to the same carrier, for ^{10}B localisation.

For recoil-proton dose separation, a method as been developed based on gels made with water and with heavy water [4].

A cylindrical polyethylene phantom, containing thin gels layers in the central transversal plane, has been exposed in the epithermal column with a base faced to the collimator. In Figure 3, the central profiles extracted from the images of the various dose components are reported vs. depth in phantom.

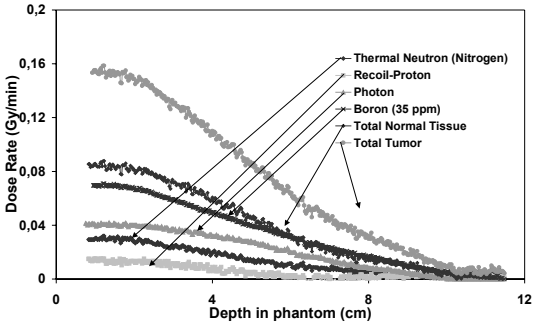

Figure 3. Profiles of dose components in a cylindrical phantom exposed in epithermal column.

Exposures of polyethylene phantom containing a cylindrical volume (6 cm diameter, 3 cm height) of gel added with proper amounts of Gd have been performed in the TAPIRO epithermal column. The isotope ^{157}Gd has a very high cross section for thermal neutrons (σ = 255000 b) giving the reaction $^{157}Gd(n,\gamma)^{158}Gd$, which is followed by emission of internal-conversion electrons and Auger electrons. Gamma and electron dose components have been separated with the proposed method. The results obtained with gel dosimeters were inter-compared with those obtained with TLDs. In Figure 4, central profiles are shown of gamma dose components in the phantom with and without Gd and the dose component due to electrons from Gd reactions. The consistency of the obtained results confirms the validity of the proposed method.

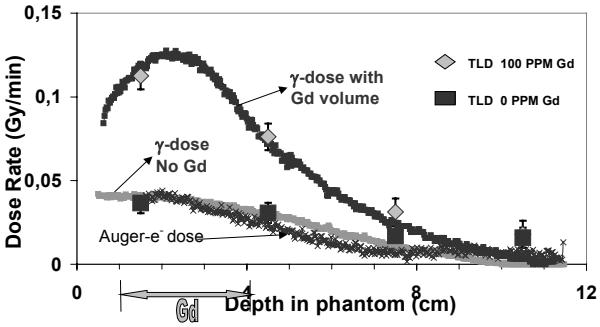

Figure 4. Gamma dose components in the phantom with and without Gd and dose component due to internal-conversionr and Auger electrons.

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