MICRODOSIMETRY AT THE TAPIRO REACTOR THERMAL NEUTRON BEAM

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ABSTRACT

By the fast reactor TAPIRO at the ENEA research centre Casaccia, a thermal column is available for dosimetric and radiobiological studies. In the frame of LNL BNCT project, the TAPIRO neutron field has been studied with a TEPC that has worked alternatively with an ordinary tissue-equivalent cathode and with a boron-enriched cathode. Measurements have been performed with polyethylene caps of different thickness. Both absorbed and biological dose show a maximum at about 0.5 mg/cm^2 of depth. The different dose components have been calculated and the results are discussed.

Introduction

The Legnaro Laboratories of the Italian institute of nuclear physics have the project of constructing a high intensity proton accelerator for fundamental studies. The project comprises the aim of using the 5 MeV and 30 mA injector proton beam for producing an intense fast neutron beam, via n+Be reaction. The final aim is producing an intense thermal neutron beam for experimental skin melanoma therapeutic studies by using the boron neutron capture therapy (BNCT) techniques[1,2]. In this frame, we are studying the possibility of using tissue-equivalent proportional-counters (TEPC) for monitoring the future therapeutic neutron beams.

We have constructed a TEPC with interchangeable cathode wall (with and without ^{10}B loaded) to study microdosimetric spectra of TAPIRO reactor with the aim of characterising its thermal column in order to perform radiobiological studies. This paper discusses the experimental information obtainable from microdosimetric spectra of 1 μm of simulated diameter, with the assumption that the TEPC sensitive volume is small enough to represent a Bragg-Gray cavity for all the radiation components. Microdosimetric spectrum, absorbed dose and biological dose variations with depth in a polyethylene phantom are studied assuming that ^{10}B is uniformly distributed in the sample.

TAPIRO is a fast reactor of 5 kW of power. A structure of graphite moderates the fast neutrons. Inside this structure there is a irradiation room of 18x19.5x22 cm^3, where the counter has been placed for the measurements.

Methods and materials

The counter

We have constructed a avalanche confinement TEPC[3], the sensitive volume of which has of 13 mm diameter and 13 mm of height. The anode is a 100 μm golden tungsten wire. A 6 mm diameter helix confines the electronic avalanche close around the anode wire. The 1 mm thick Shonka A-150 cathode wall is shaped into two shells, which can be alternatively removed and substituted with other shells. In such away, the same counter can be equipped with different boron-content cathode wall. The counter is encapsulated in a 0.2 mm thick aluminium cap. The total counter thickness is of 0.21 g/cm^2. A calibration alpha source can be inserted and removed by rotating the counter base. The three counter electrodes can be separately biased to optimise the gas gain at the given gas pressure. Although the counter is able to measure down to 50 nm[4], this study has been performed at 1 μm of simulated site size.

Measurements were performed with 100 ppm ^{10}B in the cathode wall and without ^{10}B, flowing the TEPC with dimethylether at 1 cc/min and at 4.13 kPa of pressure (equivalent to 1 μm of thickness at density 1 g/cm^3 at 20.6 °C). The counter was inserted in the TAPIRO thermal column irradiation

room. Seven polyethylene cylinder caps of different thickness (1, 2.3, 4.2, 8.2, 12.2, 20, and 35 mm) were alternatively inserted on the TEPC to collect microdosimetric spectra at different depths. Measurements have been performed with the reactor at about 25 W of power. The reactor power was precisely monitored with an ionisation chamber positioned close to the reactor core. Before calculating microdosimetric average values, spectra have been linearly extrapolated down to 0.01 keV/μm.

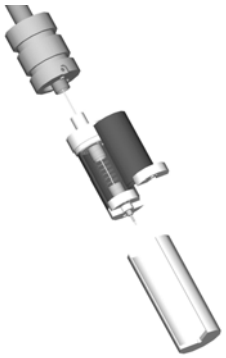

Fig.1. Artistic view of the avalanche confinement TEPC with replaceable cathode walls.

RBE assessment

The relative biological effectiveness (RBE) has been assessed by using the following equation:

$$RBE = \int r(y)d(y)dy \qquad (1)$$

where ***d(y)*** is the weighted distribution of the lineal energy ***y***. We have used the weighting function published by Loncoln et al.[10], which was calculated from radiobiological RBE values for early effects in mice at 8 Gy and microdosimetric spectra in 2 μm site. We have assumed that 1 μm spectra have negligible differences with 2 μm spectra.

Doses and biological doses

The dose $\dot{D}$ per second and per reactor power monitor unit has been calculated with the following equation:

$$\dot{D} = \frac{c \cdot \overline{y_f} \cdot \rho}{t \cdot I} \qquad (2)$$

where $\overline{y_f}$ is the mean lineal energy calculated over all the microdosimetric spectrum (extrapolated down to 0.01 keV/μm); ρ is the event rate; t is the measurement time; I the current of the reactor power monitor and c is the calibration factor. Since the TEPC response was not calibrated in a standard radiation field, dose rate data are given in relative units. Moreover, for sake of simplicity, in the following we will call the dose rate $\dot{D}$ as the dose D.

The biological dose is defined as D x RBE. Where RBE is calculated with equation 1.

Moreover we processed microdosimetric spectra to calculate the the gamma dose component (D_γ), the dose component due to He and Li ions of the ^{10}B capture reactions (D_{BNC}) and the dose component due to ions, coming from neutron reactions on tissue-equivalent plastic (D_n) both when ^{10}B is absent and present. The technique used to do that is explained elsewhere[6].

Results and discussion

Microdosimetric spectra in 1 μm site

Three of the spectra collected at different depth without ^{10}B are plotted in figure 2a. The γ-component is dominant. It increases and moves towards higher y-values with the depth. Hgher y-values events are due to protons and light ions, which arise form nitrogen neutron-capture events and fast neutron reactions. In figure 2b spectra collected with ^{10}B at the same depth are plotted. The

BNC component (the peak at about 300 keV/µm) is now dominant; it first increases and then decreases with the depth.

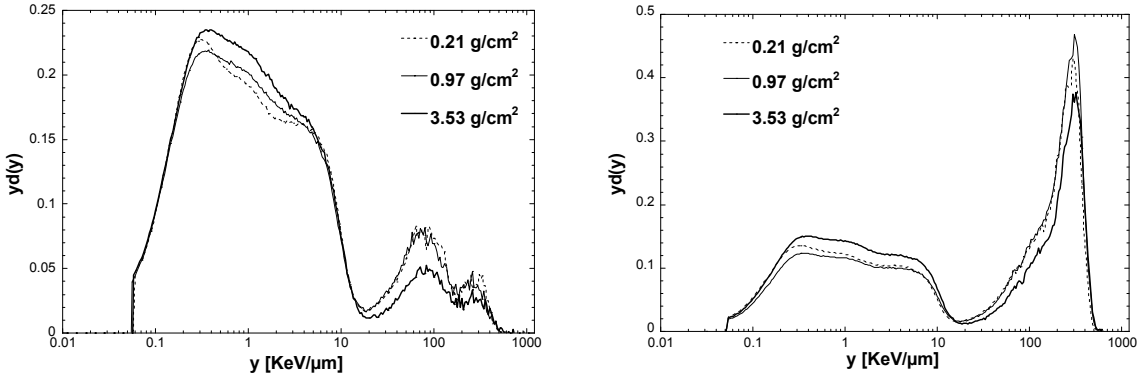

Figure 2. (a) Without ^{10}B microdosimetric spectra at different polyethylene depths ; (b) With 100 ppm ^{10}B microdosimetric spectra at different polyethylene depths.

Doses and biological doses at different depths

In figure 3a doses and biological doses, with and without ^{10}B, are plotted against the depth (cap thickness plus TEPC wall thickness). Both dose and biological dose values have been normalised at the minimum thickness ^{10}B-free dose value. Without ^{10}B, the dose is almost constant decreasing slowly with the depth. The biological dose follows the same trend, since also the RBE is almost constant, varying from 1.17 ± 0.03 to 1.30 ± 0.03. With 100 ppm of ^{10}B, the dose shows a peak at about 0.5 g/cm^2 of depth. This peak is due to thermal neutron flux, which has possibly a maximum at that depth. The neutron field inside the irradiation room is in fact not purely thermal. Epithermal and fast neutrons are present. Increasing the cap thickness, the epithermal neutron component becomes more and more thermal. However, the ^{10}B and H thermal neutron captures decrease the thermal flux. These two opposite contributions to the thermal neutron flux give rise to a maximum, the position of which depends on the neutron energy spectrum. Also in this case, the biological dose follows the dose trend, since the RBE is almost constant, varying from 1.30 ± 0.04 to 1.39 ± 0.04.

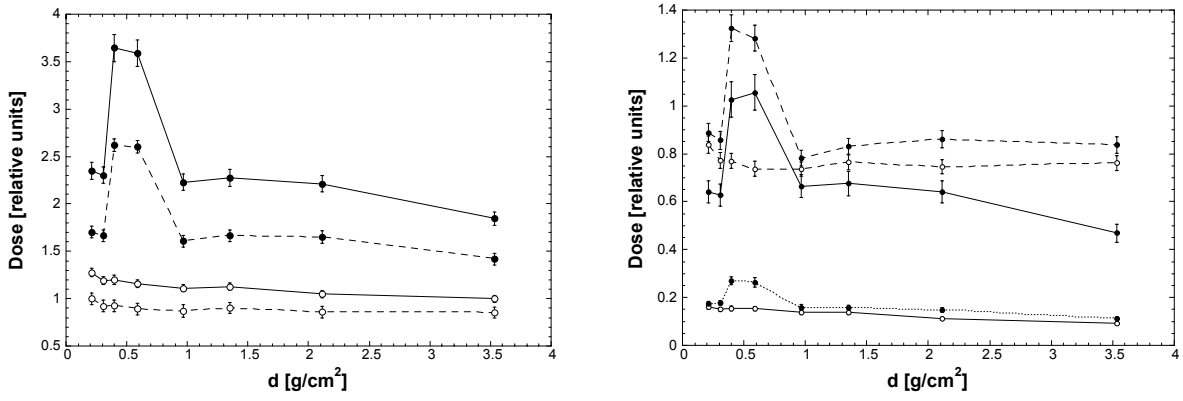

Figure 3. (a) Variation of the dose (symbols with dashed line) and of the biological dose (symbols with full line) with polyethylene thickness. Open circles: data in absence of ^{10}B. Full circles: data with 100 ppm of ^{10}B. (b) Dose component variation with polyethylene thickness in absence of ^{10}B (open circles) and with 100 ppm of ^{10}B (full circles). Dashed line: gamma-ray component. Full line: neutron-recoil component. Dot line: BNC component.

Dose components

We have processed microdosimetric spectra to know the relative dose components and their variation with depth. In figure 3b all the dose components are plotted against the depth. Data are relative to the total dose without ^{10}B at the minimum thickness.

Without ^{10}B, 80% of the dose is due to gamma rays. The slight rise with deeper depths is possibly due to an increase gamma field in the irradiation room because of an increase of the facility activation.

With 100 ppm of ^{10}B, both D_{BNC} and D_γ show peaks at 0.5 g/cm^2 of depth. This is consistent with a maximum of thermal neutron flux at that depth, which gives rise to a maximum of ^{10}B neutron captures with a maximum of reaction product yields. The gamma dose is still dominant. The D_n component is always higher than the D_n without ^{10}B. Moreover, D_n shows a small peak at 0.5 g/cm^2 of depth, similarly to D_{BNC} and D_γ. These facts have no evident physical reasons. Possibly they are due to assumption made to calculate D_n and D_{BNC}, which are not accurate[6].

Conclusions

We have constructed a TEPC, which can be assembled with tissue-equivalent cathode walls with and without ^{10}B, for studying the radiation field in the thermal column of TAPIRO reactor for future BNCT-aimed radiobiological studies. Microdosimetry has confirmed to be a powerful and precise technique for monitoring mixed radiation fields and their biological effects. However, the dose component calculations are less accurate than expected. Further measurements are therefore necessary to assess more precisely TEPC limits in monitoring the complex radiation field used in BNCT.

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