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Innovative 3D sensitive CdZnTe solid state detector for dose monitoring in Boron Neutron Capture Therapy (BNCT)

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ABSTRACT

A BNCT-dedicated SPECT system to monitor in real time the ^{10}B dose is under development focusing on CdZnTe (CZT) solid state detectors as photon sensors. Since BNCT facilities are characterised by a $(n+\gamma)$ radiation field and considering the high value of cadmium neutron absorption cross section, we evaluated the response of a CZT detector using the irradiation thermal neutron facility of the Pavia University research nuclear reactor. The reported measurements showed that, despite the thermal neutron and γ background, the CZT detector is able to discriminate the ^{10}B signal from the neutron capture peaks of ^{113}Cd.

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1. Introduction

Boron Neutron Capture Therapy (BNCT) is a hadron therapy based on the nuclear reaction ^{10}B(n,α) ^{7}Li. The released energy is selectively deposited inside the ^{10}B-enriched cells, sparing the surrounding tissues. 94% of ^{7}Li recoil nucleus produces a 478 keV prompt γ ray which can be measured by a Single Photon Emission Computed Tomography (SPECT) system thus allowing a real time ^{10}B dose monitoring.

The INFN 3CaTS project aims to develop a BNCT-dedicated SPECT using innovative 3D strip cell CdZnTe (CZT) photon detectors. To test the feasibility of this technology in BNCT applications, the response of CZT detectors to a mixed $(n+\gamma)$ radiation field should be evaluated, in particular to consider the 558 keV signal induced by thermal neutrons on ^{113}Cd [1].

2. Materials and methods

The $5 \times 5 \times 20$ mm^3 CZT detector used in this study has been developed by IMEM and due2lab S.r.l. Its characteristics, basic operational conditions and performances are reported in [2].

The experiments were carried out inside the Thermal Column (TC) of the T.R.I.G.A. Mark II research nuclear reactor of Pavia University [3]. The TC is made by graphite blocks and bismuth layers, the latter used to reduce the photon contamination coming from the reactor core. The whole TC structure is lined with a 0.3 cm thick Boral layer to absorb the escaping thermal neutrons. Inside the graphite blocks, a $100 \times 40 \times 20$ cm^3 irradiation chamber is available for BNCT experiments exploiting an isotropic neutron field. To avoid the direct irradiation of the CZT detector, a 30 cm natural lithium polyethylene (LiPoly) block with a central hole of 4 cm diameter is used to extract a neutron beam. LiPoly

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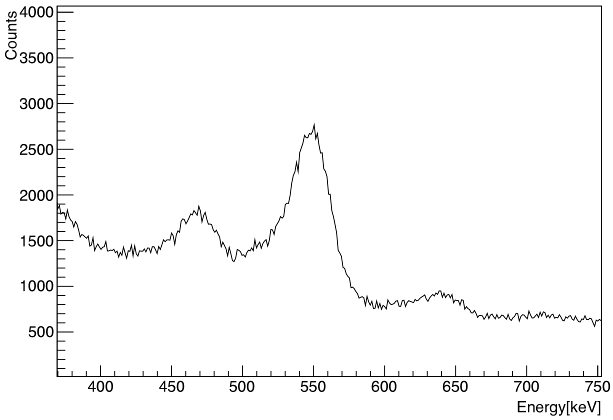

Fig. 1. γ rays spectrum recorded by the CZT detector when irradiated inside the TC of Pavia reactor. Thermal neutron flux $2.08 \cdot 10^4$ cm^{-2} s^{-1} (corresponding to 300 W reactor power), counting live time 600 s, dead time lower than 4%.

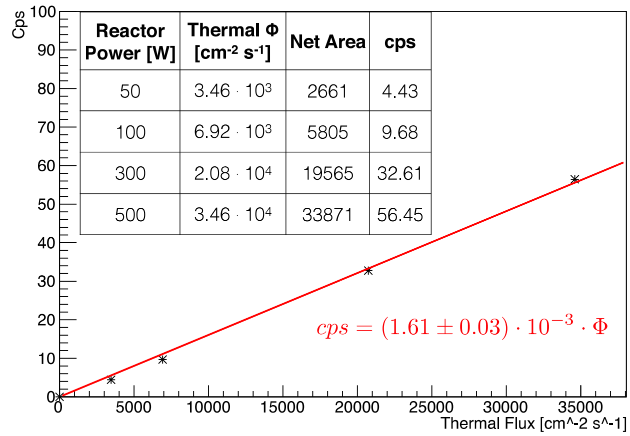

Fig. 2. Correlation between cadmium main peak counts and thermal neutron flux. The linear fit was obtained by ROOT-CERN analysis software. The errors on the simulated thermal fluxes are below 5% while those on net areas are lower than 3%, thus they are not reported in the plot.

was chosen to keep as low as possible the γ contamination in the CZT irradiation position. With respect to beam axis, the CZT detector was oriented at 90° and positioned at 1.5 cm from beam port centre. A 5 cm lead brick shielded the detector from the γ rays coming from the reactor core while a 1 cm lead foil was positioned above the detector container. No neutron shield was employed.

3. Results

The thermal neutron flux in the CZT irradiation positions was calculated by MCNP6v1 Monte Carlo code [4] and equals to $1.73 \cdot 10^7$ cm^{-2} s^{-1} at 250 kW maximum reactor power.

Fig. 1 is an example of the obtained spectra. It shows three clearly separated peaks: a peak at 478 keV, likely due to ^{10}B containing materials inside the TC structure; a peak at 558 keV corresponding to the main γ ray emission of ^{113}Cd neutron capture. This is confirmed by the third peak at 661 keV, which equals to the second most intense γ ray emitted by ^{113}Cd neutron captures. The energy resolutions are respectively 16% and 9% for the 478 keV signal and the main emission of cadmium.

In addition, we studied the behaviour of the net counting area under the 558 keV cadmium peak as function of the thermal neutron flux reaching the CZT volume. Fig. 2 shows the linear relationship between the two quantities in the reactor power range of [50–500 W].

4. Discussion

This preliminary study allows us to ascertain the response of a CZT photon detector when exposed to a mixed (n + γ) radiation field which simulates, at least qualitatively, the expected background of a clinical BNCT facility. Compared to the 3% energy resolution at 511 keV reported under ideal conditions (no radiation background; exposure to point-like standard γ sources) [2], we observe a worst energy resolutions due to the neutron background. Nonetheless, the 478 keV signal of interest in a BNCT-SPECT is clearly separated from the main γ ray due to neutron capture of ^{113}Cd. In future measurements, ^{6}Li-containing shields will be adopted to reduce the intensity of cadmium peaks, thus improving the sensitivity of 478 keV signal detection. An evident linearity is observed among the counts of the cadmium main peak and thermal neutron fluxes. This observation supports further studies to exploit CZT detectors as thermal neutron monitors, as already suggested by other authors [5].

5. Conclusion

The behaviour of a $5 \times 5 \times 20$ mm^3 CZT detector has been preliminary tested using a mixed (n + γ) radiation field, with the intention of proving the feasibility of CZT photon sensors in a BNCT-dedicated SPECT imaging system for real time ^{10}B dose monitoring. The spectra recorded at the Pavia reactor TC irradiation facility shows a significant peak at 558 keV due to the neutron capture of ^{113}Cd. Despite the lower energy resolution around 500 keV due to the neutron background, the detector discriminates properly the 478 keV peak, supporting the use of CZT crystals in our BNCT-SPECT project.

In addition, the observed linearity between the counts at 558 keV due to ^{113}Cd neutron capture and the thermal neutron flux reaching the detector opens some prospects for further applications of CZT technology as thermal neutrons monitor.

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