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Development of a Brazilian gamma–neutron dosimeter

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Abstract

Aiming to improve the neutron dosimetry in Brazil a gamma–neutron mixed field dosimeter using the techniques of TLAD and SSNTD was developed. Commercially available materials were preferentially used. The dosimeter was projected to evaluate gamma, intermediate (Albedo) and fast neutron doses from ^{241}AmBe sources. Dosimetric properties such as gamma and neutron doses and angular responses were evaluated.

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Keywords: Neutron dosimeter; SSNTD; TLAD

1. Introduction

The increasing use of neutron radiation in industrial and medical applications has multiplied the number of workers potentially exposed to neutron radiation, and the personal monitoring has to be extended to mixed fields gamma–neutron.

Neutron dosimetry is a complex technique and highly neutron energy dependent. Different materials and methods has been studied and proposed to a efficient neutron dosimetry [1,2].

The personal monitoring of Brazilian workers potentially exposed to neutron radiation is limited due to the costs of the dosimeters. Aiming to improve the neutron dosimetry in Brazil the Instituto de Pesquisas Energéticas e Nucleares – IPEN, a governmental institution, in association with PRO-RAD, a private Monitoring Service, developed a gamma–neutron mixed field dosimeter using the techniques of Albedo Thermoluninescence Dosimetry – TLAD and Solid State Nuclear Track Dosimetry – SSNTD. Low cost and commercially available materials such as polyethylene, polycarbonate and polymethylmetacrilate were preferentially used. The dosimeter was projected to evaluate gamma, intermediate (albedo) and fast neutron doses from ^{241}AmBe sources.

2. Materials and methods

The TL detectors chosen were the Harshaw TLD-700 (gamma sensitive) and TLD-600 (neutron sensitive) ribbons and the TL measures were performed using a Harshaw 200A/B TL reader.

The track detectors were obtained using a commercially available polycarbonate 1.5 mm thick named SS-1 described in Souto and Campos [3]. The chemical etching was performed using the PEW-40 solution at 75 °C during 3 h [4]. A video camera connected to an optical microscope was used to track counting.

The photon irradiations with effective energy close to ^{241}Am gamma energy were performed using RQA 7 X-ray beam quality from an industrial X-ray equipment, in free air and ambient temperature. The neutron irradiations

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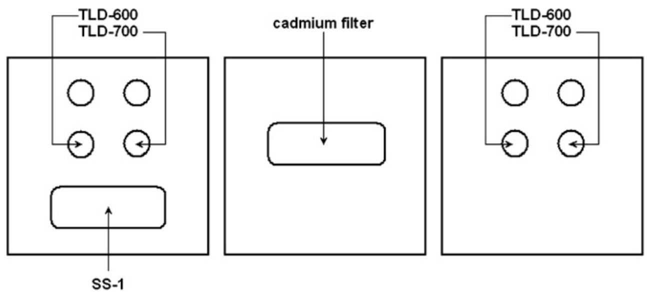

Fig. 1. Internal view of the neutron dosimeter.

were carried out using an ^{241}AmBe source, 185 GBq, and the prototypes were displaced on an ISO slab phantom.

3. Prototype description

The dosimeter prototype (Fig. 1) consists of a sandwich of three polyethylene plates 1.0 mm thick with holes to support the detectors (TL and SSNT) and a cadmium filter between two PMMA support plates 1.5 mm thick that provides the SS-1 shielding to natural radon. The TL sensitive materials (two TLD-700/TLD-600 pairs) are positioned in the frontal and rear plates respectively, with a cadmium filter between them used to shield thermal neutrons, positioned in the middle plate. The SS-1 detector is also positioned in the frontal plate. The four available TL positions can be used to diverse purposes.

4. Response evaluation

Incident thermal neutrons and gamma radiation are detected by the TL detector pair positioned in the frontal position. Albedo neutrons (intermediate neutrons backscattered by the body) are detected by the rear TL-600 detector. The cadmium filter shield thermal neutrons, so incident thermal neutrons will not interact with the second TLD-600 detector nor albedo neutrons will interact with the first TLD-600 detector. Fast neutrons are detected by the SS-1 detector. The ratio of incident thermal, albedo and fast neutron responses allows analyzing the energy spectrum to which the dosimetry was submitted and correcting the track detector response to variations in the radiation incidence angle.

Fig. 2 shows the dosimeter dose response to gamma, incident and albedo neutrons.

The minimum detectable gamma dose, calculated according to ISO/DIS 21909 [5], is lower than 0.1 mSv.

The neutron dose can be calculated utilizing only albedo or fast neutrons response. The thermal neutrons response of ^{241}AmBe sources depends on neutron moderation and scattering caused from the source to the detector.

The albedo neutron response is linear in the studied range, whereas the fast neutron response is linear just between 1 and 20 mSv (Fig. 2). Above 20 mSv, it presents a saturation tendency in the SS-1 response. The minimum detectable dose is 0.12 mSv to fast neutrons and lower than 0.1 mSv to albedo neutrons.

The ratio of albedo and thermal neutron responses is constant in the studied range (0.5–500 mSv). This ratio provides the spectral neutron energy distribution, that is, a different ratio indicates that the dosimeter was not irradiated with ^{241}AmBe. In the interest dose range, up to 20 mSv (ISO/DIS 21909), the variation of the ratio of fast and albedo neutron responses is also negligible (Fig. 3).

The angular response variation to thermal and albedo neutrons is acceptable (ISO/DIS 21909), instead of fast neutrons response, which could be corrected. The behavior of fast neutron angular response seems to be a cosine function (Fig. 4). Knowing the radiation incidence angle, the SS-1 response can be corrected by a factor equal to the inverse of this angle's cosine. The incidence angle is evaluated through the variation of the ratio of fast and albedo

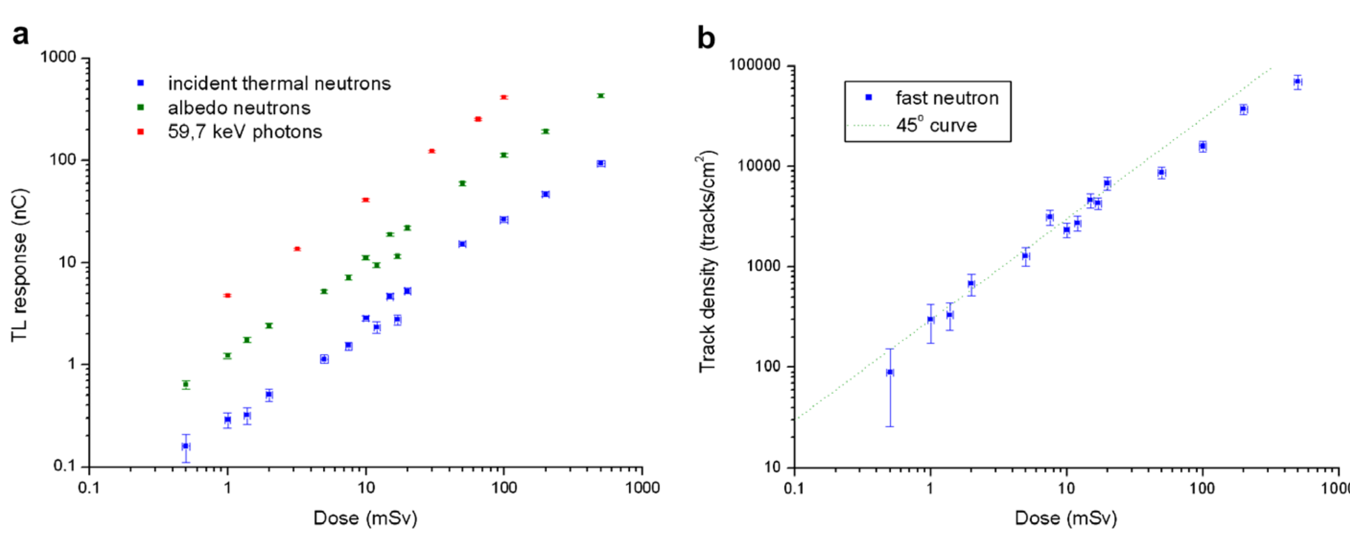

Fig. 2. (a) Gamma, incident and albedo dose response and (b) fast neutron dose response.

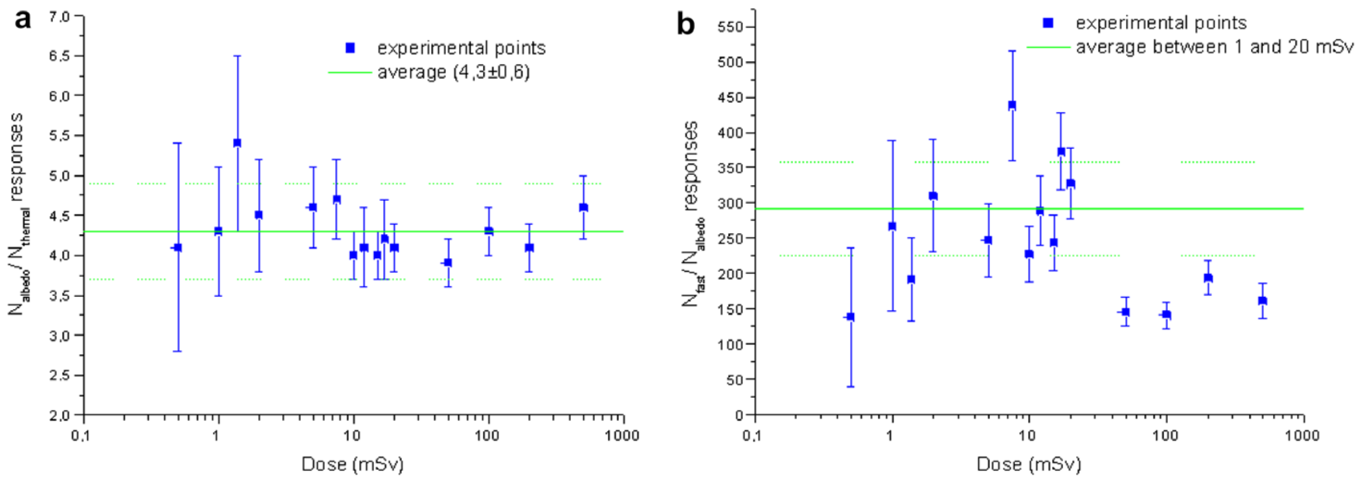

Fig. 3. Albedo to incident and albedo to fast neutron responses ratios.

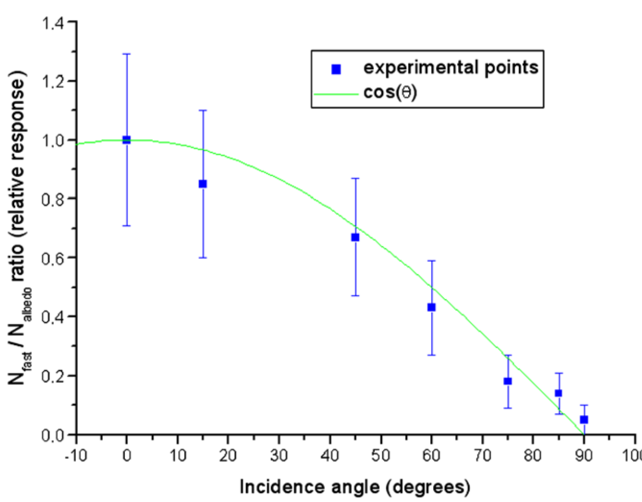

Fig. 4. Fast neutron angular response of the dosimeter.

neutron responses. This ratio has liner behavior with the radiation incidence angle.

The dose algorithms are very simple: gamma, albedo neutrons and fast neutrons doses are estimated by linear equations extracted from the graphics of Fig. 2. Since the SS-1 track counting is very hard and tedious, the neutron dose is preferentially estimated by albedo neutrons. Just to high doses confirmation or when TLD responses are lost, the fast neutron response is used.

The ratio of albedo and thermal neutron responses is constant, either under dose and angle variation. If this ratio is different from the expected value, the dosimeter was not irradiated with ^{241}AmBe or there is disturbing materials from the source to the dosimeter. In this case, the dose algorithms fail and cannot be used.

The ratio of fast and albedo neutron responses decreases with the incidence angle, due to the high angular dependence of SS-1 response. This variation allows estimating the incidence angle and, then, correcting the fast neutron dose.

The combined use of these two dosimetric techniques, TLD and SSNTD also allows verifying the correct use of the dosimeter. A high thermal neutrons response and low fast neutron response, indicates that the dosimeter was use back turned to the source or on the back of the user. In the same way, a high fast neutrons response and low albedo neutrons response indicates that the dosimeter was used far from the user's body or was irradiated with no user.

5. Conclusions

The algorithm to dose estimation is very simple, but is valid only to ^{241}AmBe sources; to use this dosimeter for other neutron spectrum, a new calibration is need.

The ratio of thermal, albedo and fast neutrons responses are parameters to correcting the angular dependence and evaluating the spectrum and the correct use of the dosimeter.

The proposed dosimeter presents low cost and can easily be produced in Brazil, their performance is adequate according to ISO/DIS 21909, indicating that the dosimeter can be used to personal neutron monitoring.

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