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Improving the neutron-to-photon discrimination capability of detectors used for neutron dosimetry in high energy photon beam radiotherapy

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HIGHLIGHTS

- Neutron-to-photon discrimination of a thermal neutron detector used in radiotherapy.
- Photon and anisotropic response study with distance and beam incidence of thermal neutron detector.
- Borated rubber for estimating photon contribution in any thermal neutron detector.

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ABSTRACT

The increasing interest of the medical community to radioinduced second malignancies due to photoneutrons in patients undergoing high-energy radiotherapy, has stimulated in recent years the study of peripheral doses, including the development of some dedicated active detectors. Although these devices are designed to respond to neutrons only, their parasitic photon response is usually not identically zero and anisotropic. The impact of these facts on measurement accuracy can be important, especially in points close to the photon field-edge.

A simple method to estimate the photon contribution to detector readings is to cover it with a thermal neutron absorber with reduced secondary photon emission, such as a borated rubber. This technique was applied to the TNRD (Thermal Neutron Rate Detector), recently validated for thermal neutron measurements in high-energy photon radiotherapy. The positive results, together with the accessibility of the method, encourage its application to other detectors and different clinical scenarios.

1. Introduction

New radiotherapy techniques, such as those with intensity modulation of the beam fluence, reduce the amount of healthy tissue exposed to high radiation doses. However, and due to their greater demand in terms of Monitor Units (MU), these techniques have been found to increase the out-of field doses (Xu et al., 2008). The latter, together with the larger survival after radiotherapy treatments, have made the incidence of late effects, such as second malignant neoplasms more relevant. Therefore, an important number of dosimetry studies have been conducted to determine peripheral doses more accurately. These doses have two main components: leakage/scattered photons and neutron contamination. Since dosimetric methods for photon doses are well-known (Sánchez-Nieto et al., 2015; Taddei et al., 2013), our group has focused on the neutron component, and established a methodology to estimate peripheral neutron doses (Sánchez-Doblado et al., 2012; Expósito et al., 2013; Romero-Expósito et al., 2015; Vazquez-Luque et al., 2013). Although this procedure was developed for a particular thermal neutron detector (Gómez et al., 2010), could be applicable to any other (Guardiola et al., 2013; Bedogni et al., 2014).

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Specifically, one of these detectors, named *TNRD (Thermal Neutron Rate Detector),* designed and developed by Bedogni et al., was characterized for peripheral neutron dose measurements in radiotherapy environments, according to the methodology described in Sánchez-Doblado et al. (2012). The *TNRD* showed satisfactory performances in terms of user friendliness and high sensitivity (Irazola et al., 2014). Nevertheless, recent experiments with the detector located 'in-phantom' close to the field-edge, indicated the need for further investigations about the TNRD residual photon sensitivity. Although several previous exhaustive studies in terms of electronic, cable length and detector aging, the problems was found to be related with photon rejection and detector anisotropy under some critical conditions (Irazola et al., 2015a; Praena et al., 2015; Irazola et al., 2016; Irazola et al., 2015b; Irazola et al., 2015c). These parasitic effects were directly observed during exposures with ^{60}Co and 6 MV Linac (Terron et al., 2015), where no neutrons are present. Nevertheless, no experiment succeeded in clearly separating photon and neutron signals in a high-energy irradiation.

This paper proposes a simple method to estimate photon contribution to TNRD readings through by simply covering the detector with a thermal neutron absorber (with reduced secondary photon emission), such as a borated rubber. For the present work a commercial material, called Flex-Boron®, (http://www.deqtech.com/Shieldwerx/Data_Sheets/SWX-238.pdf), was used. This material (Gómez et al., 2010; D'Mellow et al., 2007) is expected to reduce incident thermal neutron field to less than 1%. Thus, the pure thermal neutron reading of a detector can be obtained by subtracting the reading of the rubber-covered detector to the uncovered one.

2. Material and method

2.1. TNRD detector

TNRD detector, was developed by Bedogni et al. (2014) in the framework of the NESCOFI@BTF project (2011–2013, Scientific Commission V, INFN-LNF, Italy), is based on a low-cost commercial solid-state device made sensitive to thermal neutrons through a customized physical–chemical treatment (mainly consisting on a ^{6}Li deposition layer). Its active area is 1 cm^2 and its overall dimensions are 1.5 cm × 1 cm × 0.4 cm (Fig. 1). Its output is a DC voltage, which is proportional to the thermal neutron fluence rate (for this reason the device is called "rate detector"). This signal is amplified in a low-voltage electronics module especially developed by the project team. The amplified output is sent to a programmable ADC (NI USB-6218 BNC, 16 bit, up to 250 kilo samples per second) controlled by a PC through a LabView application.

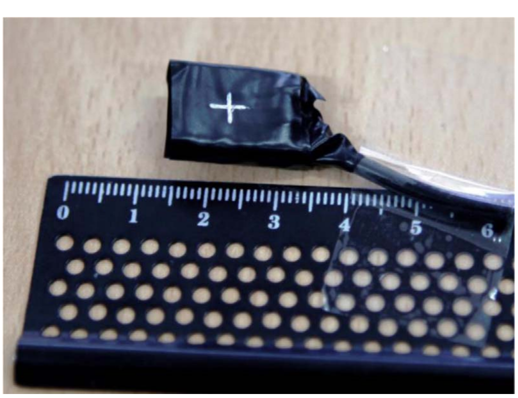

Fig. 1. TNRD (Thermal Neutron Rate Detector).

TNRD linearly responds to thermal neutron fluence rates from 10^2 up to 10^6 cm^{-2} s^{-1}. Every single *TNRD* (Fig. 1) is individually calibrated by exposing it in a suitable reference thermal field (Bedogni et al., 2016). Detector-to-detector response variability is in the order of ±5% (1 SD).

2.2. The borated rubber

Prior to its use, the borated rubber was characterized in terms of photon absorption and compared to polystyrene, used as a surrogate of human tissue in neutron experiments. A layer of 0.32 cm (ρ=1.64 g/cm^3) was found to be equivalent to 0.5 cm of polystyrene (ρ=1.05 g/cm^3). This equivalence does not depend on the primary photon field energy, since the out-of-axis photon spectrum is invariably composed by photons below 0.5 MeV (D'Mellow et al., 2007; Chofor et al., 2012). In addition, due to the high neutron capture cross section of ^{10}B, the borated rubber acts as an efficient neutron absorber (Guardiola et al., 2013; http://www.johncaunt.com/shielding/neutron-shielding/jc238/), with a nominal thermal neutron transmission factor of 3.8 × 10^{-3}. Two layers of Flex-boron® (dimensions 0.32 cm × 5 cm × 20 cm) were used to shield on both sides the detectors used here.

2.3. Irradiation tests

Exposures were performed in a Siemens Primus Linac (6 and 15 MV) at Hospital Universitario Virgen Macarena, Seville (Spain) for a 40 × 10 cm^2 field, 300 MU and 300 MU/min dose rate (1 MU equivalent to 1 cGy under reference conditions, e.g. 10 × 10 cm^2, gantry 0°, source-axis distance 100 cm, depth of maximum for each energy in water). The following types of test were performed:

(a) Free-in-air measurements

Free-in-air thermal neutron measurements, during patient treatments, are performed with bare detectors located in front of the couch, at about 3 m distance (Expósito et al., 2013) (Fig. 2). Results from these measurements are routinely used for peripheral neutron dose estimations, using the methodology established in Sánchez-Doblado et al. (2012). Negligible photon contribution to TNRD reading was expected at this location. One session of breast treatment was selected for this study, consisting in two high-energy beam (15 MV) incidences (122° and 300°), of 8 MU each one, combined with the rest of the treatment (168 MU) delivered in low energy (6 MV) the same incidences.

(b) Distance

Out-of-field photon doses were measured by means of a Farmer type ionization chamber (PTW 30013), operated at −250 V and acquired with a PTW Unidos electrometer. Detector was inserted in a set of plastic layers simulating 'in-phantom' conditions

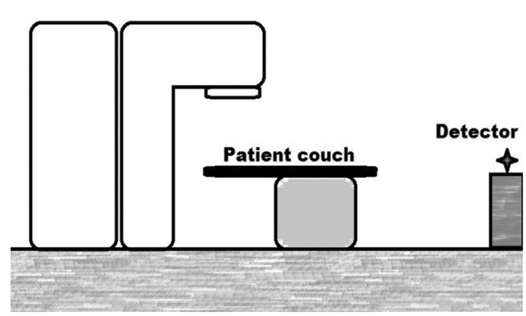

Fig. 2. TNRD location for patient measurements (free-in-air).