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The β-ray energy and angular response of the EYE-D™ eye-lens dosemeter

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HIGHLIGHTS

- The applicability of EYE-D™ eye-lens dosemeter in external β-ray fields have been investigated.
- Measurements and calculations β-ray energy and angular response of EYE-D™ have been performed.
- A comparison of calculations results with experimental data is presented.
- Obtained results confirmed the suitability of this dosemeter in assessing Hp(3) to estimate the eye lens.

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ABSTRACT

Following the recent ICRP recommendation to decrease the limit of occupational exposure to the eye lens from 150 mSv to 20 mSv/year, a dedicated individual eye-lens dosemeter, EYE-D™, was developed at the IFJ PAN. This dosemeter uses MCP-N (LiF:Mg,Cu,P) thermoluminescent detectors covered with a polyamide capsule and was so far optimized to achieve a flat photon energy and angular response for X-ray exposures typical in interventional radiology. To verify the applicability of this eye-lens dosemeter in external β-ray fields which arise, e.g. in nuclear medicine procedures, we measured and calculated its β-ray energy and angular response. Measurements, applying β-rays from Sr-90/Y-90 isotope, were performed at the Beta Secondary Standard type 2 (BSS 2) in CLOR. Calculations, using the PENELOPE Monte Carlo transport code which simulates coupled electron and photon transport in arbitrary materials, were performed for P-32, K-42 and Sr-90/Y-90 fields to simulate doses received by the eye lens within the human body. PENELOPE Monte Carlo transport code was also used to calculate doses received with EYE-D™ detectors. We found good agreement between the measured and calculated energy and angular responses which confirms the suitability of this dosemeter in assessing Hp(3) to estimate the eye lens. Obtained results and conclusions, however preliminary, conform with current ICRP recommendations when performing individual radiation protection dosimetry in external β-ray fields occurring in nuclear industry and nuclear medicine activities.

1. Introduction

Due to their small size, sensitivity and needless power supply, thermoluminescent detectors (TLDs) are widely used in personal and environmental dosimetry of ionising radiation. Significant development of TLD materials to adapt TL dosimetry to various applications in radiation protection dosimetry, has occurred (McKinlay, 1981).

The International Commission on Radiation Units and Measurements (ICRU) recommends the personal dose equivalent, Hp(d), to be used as an approximation of the effective dose in personal dosemeter calibration (ICRU, 1998, 2007).

Concern has been raised that enhanced radiation-related lens opacity occurs in interventional radiologists (Vañó et al., 1998) and in space crews (Cucinotta et al., 2001). Of concern in this aspect may also be the β-ray contribution to the personal dose equivalent in individual monitoring. While in most cases the β-ray contribution to the overall exposure is much lower than that of photons, β-ray dosimetry is becoming more important in various applications of ionising radiation in nuclear medicine and nuclear industry. In several cases, individual dosemeters applied in such conditions were not able to accurately determine the personal dose equivalent when large incident angles and low energies of β-rays were encountered (Helmstädter and Ambrosi, 1998).

Measurements of the response of individual dosemeters to external β-ray fields are difficult to perform and interpret. They

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should, therefore, always be accompanied by suitable Monte Carlo simulations of the transport of radiation, and of electrons and photons in particular (Rogers, 2006). These simulations may concern local and global characteristics of radiation fields and of the energy imparted by radiation to matter, or the human body in order to relate the locally absorbed dose to operational ICRP-recommended quantities, such as Hp(d) (ICRU, 1998; ICRP, 2007).

The aim of this study was measure the energy and angular response of a new EYE-D™ dosemeter (Bilski et al., 2011) in order to monitor Hp(3) for different beta emitters, and to back-up and interpret these measurements by suitable Monte Carlo simulations. The ultimate aim of this work was to ascertain the suitability of the dedicated individual EYE-D™ eye-lens dosemeter developed at the IFJ PAN, to correctly evaluate Hp(3) when used in nuclear medicine or nuclear industry laboratories where a significant β-ray component of the external radiation field may occur.

2. Materials and method

2.1. The measurement

2.1.1. Geometry

In operational radiation protection a depth of 3 mm, is used to approximate the dose to the lens of the eye. The personal dose equivalent Hp(3) is defined as the dose equivalent in tissue at 3 mm below the dosemeter. For beta electrons Hp(3) is equal to the absorbed dose as quality factor Q equal to 1 is recommended (Dietze and Alberts, 2004; ICRP, 2007).

For this quantity, a new cylindrical phantom to better reproduce the head was proposed (20 cm $\times$ 20 cm) (Gualdrini et al., 2011).

The layout of the geometry used in measurements and calculations is given in Fig. 1. A 20 cm diameter 20 cm height cylinder with 0.5 cm polymethyl methacrylate (PMMA) walls, filled with water was used and EYE-D™ dosemeters are placed on the mid plane of this phantom in 0°, 20°, 30° and 45° positions. The angles greater than 0° are worth special attention as the doctors usually worn detectors on the side of the head. The active element of the dosemeter is an MCP-N (LiF:Mg,Cu,P) thermoluminescent detector covered with a 3 mm thick polyamide capsule. The composition of the MCP-N (LiF: Mg,Cu,P) detector is Mg (0.2 M%), Cu (1.25 M%) and P(0.05 M%) (Horowitz et al., 2012) and the TLDs are sintered pellets of diameter 4.5 mm and 0.9 mm thick, developed and manufactured at the IFJ PAN in Krakow, Poland.

2.1.2. Exposures and readout of detectors

The dosemeters EYE-D™ were irradiated at the Beta Secondary Standard type 2 (BSS 2) in Central Laboratory for Radiological Protection (CLOR), Warsaw, Poland, using Sr-90/Y-90 source with a beam-flattening filter to provide homogeneity of dose (Ambrosi et al., 2007). EYE-D™ dosemeters with MCP-N detectors inside were placed in front of the water filled cylindrical phantom in 0°, 20°, 30° and 45° positions and exposed to Sr-90/Y-90 β-ray beam (Fig. 2). With activity of the source of 330 MBq, the personal dose equivalent at a depth of 3 mm, Hp(3), was 8.62 mSv at a reference source-detector distance of 30 cm with an angle 0° (Fig. 2). Detectors, thus, were irradiated by almost half of the annual limit recommended for Hp(3) for workers. The nominal value of the Hp(3) was assessed from Hp(0.07) with a correction factor of 0.4311 given by Behrens (Behrens and Buchholz, 2011). This value refers only to the front detector (angle 0°) to which all other readouts were normalized. Measurements as well as irradiation conditions fulfil requirements given by ISO standard of 6980 series (ISO 6980-1, 2006; ISO 6980-2, 2004; ISO 6980-3, 2006). After irradiation, TLDs were put in RADOS badges which were placed in a cassette and then detectors were annealed in the owen and readout at 260 °C for 16 s with a use of an automatic RE-2000 (Mirion Technology Oy) hot-gas reader. The energy and angular response was obtained by measure the intensity of the integrated TL signal (area under the glow peak)(see Fig. 3).

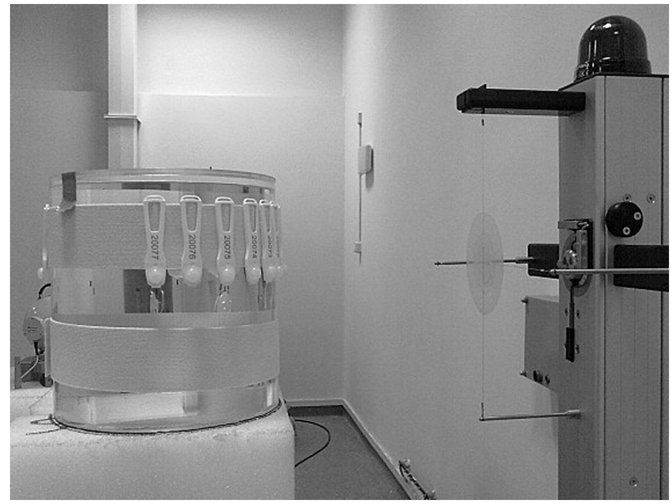

Fig. 2. Picture showing irradiations in Laboratory at CLOR Warsaw.

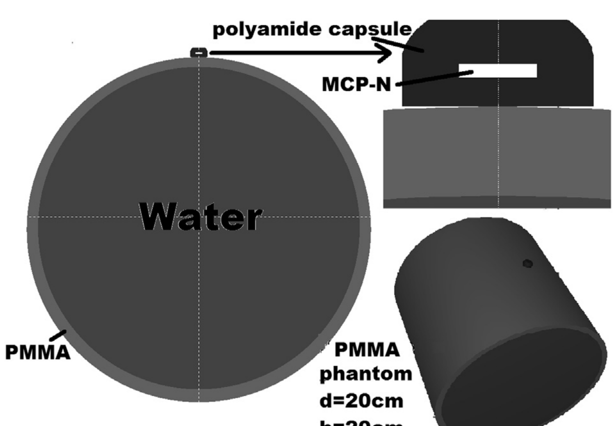

Fig. 1. General scheme of geometry applied for calculations.

2.2. The simulations

The MC simulations were performed using the PENELOPE (Penetration and ENErgy LOss of Positrons and Electrons) code, a

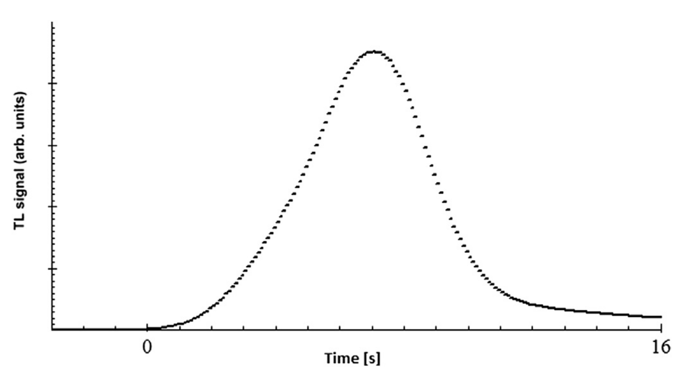

Fig. 3. TL glow-curve of MCP-N.