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Imaging of gamma and neutron dose distributions at LVR-15 epithermal beam by means of FGLDs

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ABSTRACT

Gamma and fast neutron dose spatial distributions have been measured at the collimator exit of the epithermal neutron beam of LVR-15 reactor (Řež). Measurements were performed by means of optically analyzed Fricke-gel-layer detectors. The separation of the two dose contributions has been achieved by suitable pixel-to-pixel elaboration of the light transmittance images of Fricke-gel-layer detectors prepared with water and heavy water.

1. Introduction

Some measurements have been carried out with the aim of gamma and fast neutron dose imaging at the collimator exit of the epithermal column of the LVR-15 research reactor in Řež (CZ). Particular care was devoted to fast neutron dose determination: in fact its contribution is not negligible and its biological effectiveness is high. Images of free beam doses were achieved by means of Fricke-gel-layer detectors (FGLD), placed facing the collimator mouth.

2. Materials and methods

Dose images at the epithermal column exit were attained by means of FGLDs, exploiting a method proposed and developed in the laboratory. The dosimeters are prepared in form of layer (3 mm thick) and are composed of ferrous xylenol orange gelatine gel. The dosimeters are radiochromic and light transmittance images are detected, before and after irradiation, by means of a CCD camera with an optical band-pass filter around 585 nm. The difference of optical density Δ(OD) is proportional to the absorbed dose, up to saturation (Gambarini et al., 2006).

Measurements were performed with couples of FGLDs having similar chemical composition, but prepared one with water and the other with heavy water, as requested by the method for separating gamma and fast neutron doses by means of gel layer dosimeters (Gambarini et al., 2001). The method has been recently improved, in particular to amend possible thickness non-uniformity in gel-layer dosimeters (Carrara et al., 2009). In fact, the dosimeters are handmade and thickness non-uniformity is not negligible in the larger ones (with 18 cm of diameter). The method is based on an analytical comparison of the absorbed doses in the gel layers consisting of light and heavy aqueous solutions. In the first material, fast neutron dose is mainly due to recoil protons, while in the second one to recoil deuterons. The experimental procedure for separating gamma and fast neutron doses from the dose images obtained by means of the water and heavy water FGLDs is based on suitably developed algorithms (Gambarini et al., 2010) in which some parameters have to be introduced: (i) the sensitivity to photons of each dosimeter, (ii) the ratio R of the energies released by recoil protons and recoil deuterons, (iii) the relative sensitivity, with respect to photons, of gel dosimeters to the radiation with different LET, that is to slow protons for the standard gel dosimeters and to slow deuterons for heavy-water-made gel dosimeters. The parameters of points (ii) and (iii) are energy dependent. Concerning point (ii), Monte Carlo calculations with the MCNP5 code have been performed to investigate the trend of the ratio R, utilizing the energy spectrum of the epithermal neutron beam of LVR-15 reactor. A constant value of 0.665 ± 0.001, obtained as weighted average, has been finally adopted. Concerning point (iii), for the Fricke gel sensitivity to protons, it was considered that recoil protons release most energy at the end of their path (Bragg peak). From literature (Bäck et al., 1999) the height of a Bragg peak measured with gel dosimeters (calibrated with photons) results to be 85% lower

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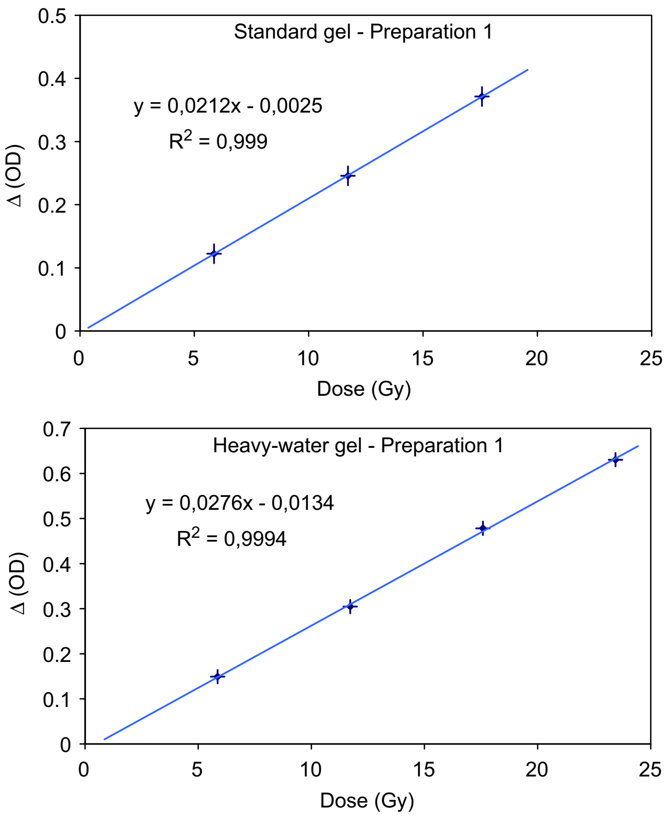

Fig. 1. Examples of calibration curves (Δ(OD) vs absorbed dose).

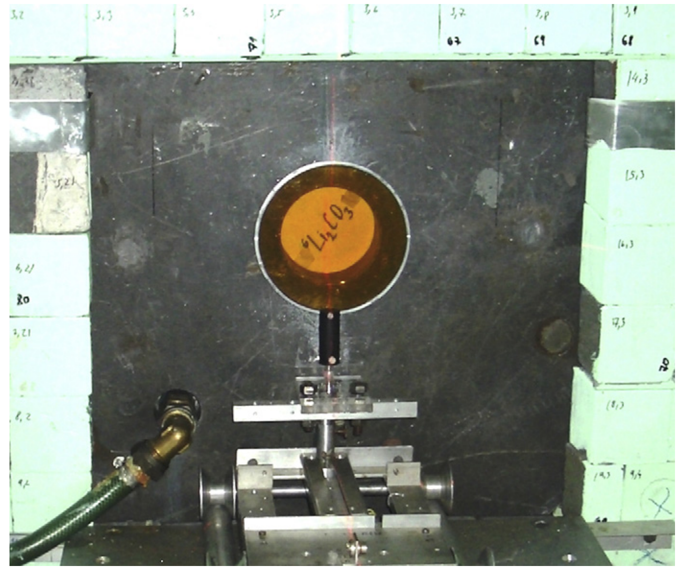

Fig. 2. FGDL against the LVR-15 epithermal column mouth.

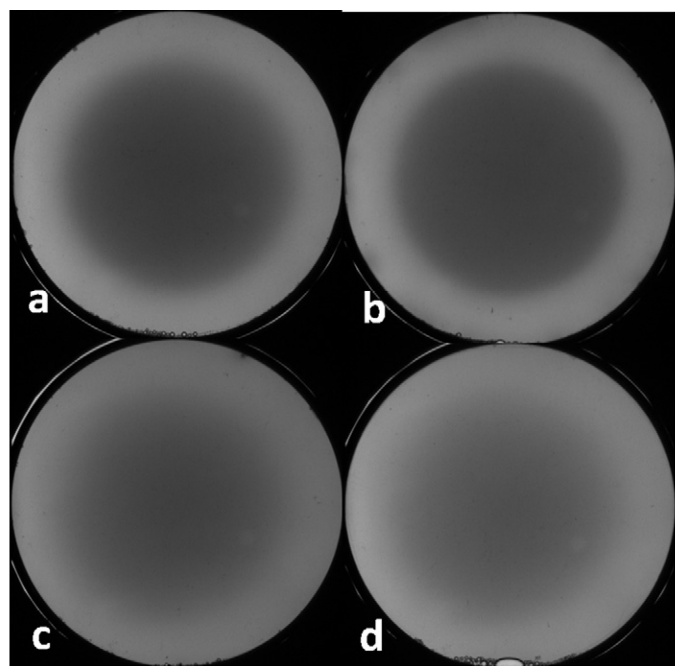

Fig. 3. Transmittance images of standard (a, c) and heavy-water (b, d) gel dosimeters irradiated at a distance of 1 cm (a, b) or 6 cm (c, d) from the collimator edge.

than the real one. So, for the relative response to protons with respect to photons the coefficient 0.85 has been assumed. No experimental data about Fricke gel sensitivity to deuterons were available in literature. Therefore, some general considerations regarding Fricke dosimeter sensitivity dependence on radiation LET have been performed and a sensitivity to deuterons with respect to photons of 55% has been chosen.

In order to perform dosimeter calibrations, for each gel preparation some small dosimeters (circular, with a diameter of 5 cm) have been set up. The calibration has been performed exposing the dosimeters to a photon beam, at a radiotherapy unit of the Istituto Nazionale Tumori (Milan), with suitable modality in order to have a uniform and known absorbed dose in each of them. To this aim, the dosimeters were placed in an suitably designed tissue-equivalent phantom, at the depth of the maximum dose. Such calibrations have been executed some days before or after the measurements at LVR-15 reactor and no correction was made for eventual variation of dosimeter sensitivity during time. A more reliable method of calibration is now in study. In Fig. 1, examples of calibration curves are reported.

The FGLDs prepared for measurements were circular, with a diameter of 18 cm. The dosimeters have been put against the LVR-15 reactor collimator mouth that is circular with 12 cm of diameter. In Fig. 2, a dosimeter positioned for irradiation is shown. Most measurements were performed with dosimeters at a distance of 1 cm from the mouth edge. Two irradiations (one standard and one heavy-water gel) were done with the dosimeters at a distance of 6 cm from the edge. For each dosimeter, light transmittance images have been acquired with the CCD camera, before and after irradiation, and the Δ(OD) image has been obtained. By pixel-to-pixel manipulation of the Δ(OD) images of dosimeters made with water and with heavy water, by means of the properly developed software containing the suitable algorithms, gamma and fast neutron doses have been separated.

3. Results

In Fig. 3, transmittance images acquired with the CCD camera are shown. Images (a) and (b) are of standard and heavy-water gel dosimeters, respectively, positioned at 1 cm from the collimator edge. Images (c) and (d) are of standard and heavy-water gel dosimeters, respectively, placed at 6 cm from the edge.

The transmittance images were analyzed with the dedicated software, in order to amend artifacts and to obtain Δ(OD) images. From the images, horizontal and vertical dose profiles can be