RADIOCHROMIC FILM AS A DOSIMETRIC TOOL FOR LOW ENERGY PROTON BEAMS

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Abstract

We tested EBT3 and HDV2 models of GAFCHROMIC™ films for dose measurements at low energy proton beam quality. Proton beam (CS30 Cyclotron at KFSHRC) has energy of 26.5 MeV and Bragg peak position at 6 mm depth. Beam output was calibrated using TRS-398 reference dosimetry protocol with calibrated ion-chamber in water and the film was calibrated in terms of dose to water by exposing calibration film pieces within a solid water phantom at depth of 3 mm. Pieces of EBT3 films were irradiated to doses of up to 10 Gy with both 4 MV photon and 26.5 MeV proton beams, while pieces of the HDV2 radiochromic films were irradiated to doses of up to 128 Gy in proton beam. Irradiated pieces of the EBT3 films were tested for activation using Germanium detector and by measuring and subsequently decomposing decay curve over a period of 40 minutes after irradiation.

EBT3 film model response was 3 times higher for 26.5 MeV proton than 4 MV photon beam quality, and when irradiated in proton beam the EBT3 film model was 24 times more sensitive than HDV2 film model. For the EBT3 film model we identified three proton-activation processes resulting in short-lived ^{15}O, ^{13}N, and ^{11}C radioisotopes. The EBT3 film model can be used for measurements for doses of up to 10 Gy using a green colour channel of the scanned images, while the red colour channel of the HDV2 scanned film images can be used for measurements of much higher doses.

INTRODUCTION

External radiotherapy proton beams commonly range in energies between 70 to 250 MeV and are produced using dedicated synchrotrons. Our institution, KFSH&RC, is in a possession of a CS-30 cyclotron which is a positive ion machine capable of accelerating four different particles: protons at 26 MeV, deuterons at 15 MeV, Helium-3 at 38 MeV and Helium-4 at 30 MeV. Accurate dosimetric characterization of a radiation field is crucial for its subsequent use in both research and clinical applications. As a part of our research project in adapting the CS-30 cyclotron for research irradiations (of cells and small animals) as well as intraoperative radiotherapy with protons (pIORT), we developed a radiochromic film based reference dosimetry system for 26 MeV proton beam.

Because of their ability to minimize beam perturbation effects caused by the presence of dosimeter body (i.e. such in ionization chambers), and because of their structure that match biological tissue in energy absorption and transfer properties, the use of tissue equivalent and energy independent radiochromic films became an interesting investigational path in proton beam dosimetry. Radiochromic film (RCF) [1,2] is a 2D high resolution dosimeter that is convenient for in vivo and in vitro dose measurements [3,4]. It has all advantages of conventional radiographic film systems without the need for wet processors, making this film type an important dosimetric tool. They can be cut in any arbitrary shape or size and can be handled in ambient light with much less detriment compared to radiographic film. In addition, they have properties equivalent to those of water and have been shown to have a response independent of beam quality in a relatively broad energy range including proton beams [5].

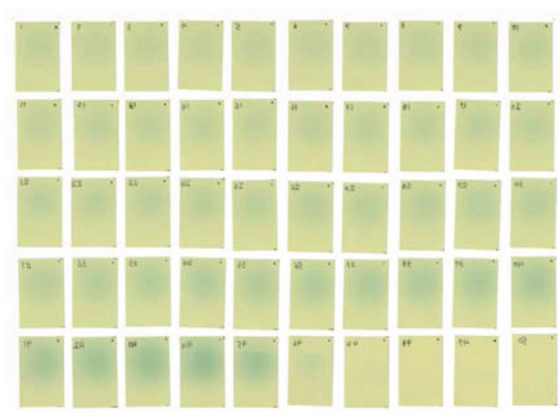

Figure 1: Pieces of HDV2 GAFCHROMIC™ film model stacked together within a plastic phantom in order to measure the per cent depth dose of the proton beam.

Relatively high dose rate of the CS-30 proton beam, which is characteristic of cyclotrons used for radiopharmaceutical production, requires use of a less sensitive radiochromic film model. The HD-V2 model GAFCROMIC™ film was introduced recently as a replacement of the previous HD-810 film model. It has a dynamic range between 10 – 1000 Gy and it was introduced for Gamma Knife and Stereotactic Radio Surgery (SRS) quality assurance and commissioning processes in addition to other industrial applications. It has a nominal thickness of 105 microns consisting of an 8 microns active layer and a 97 microns polyester substrate. The advancement over the HD-810 model is attributed to the addition of a yellow dye marker which is anticipated to correct for inhomogeneities arising from variation in the

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active layer thickness. This property was initially introduced in the EBT2 film model that is used for dosimetry of high energy photon beams [6].

MATERIALS AND METHODS

As a first step in our radiochromic film dosimetry protocol we performed measurement of per cent depth dose using 50 pieces of HDV2 model GAFCHROMIC™ films (Fig. 1), with a nominal thickness of 0.11 mm (0.15 mm water equivalent thickness), stacked together within a plastic phantom and placed orthogonally to the direction of the proton beam.

Film pieces were scanned prior to and 24 hours after irradiations using a 48-bit RGB an Epson Expression 10000XL flatbed document scanner (Epson, Nagano, Japan) in the transmission mode and an image resolution of 127 dpi. Film pieces were handheld in accordance to with the AAPM TG-55 protocol. Response of film pieces was measured in terms of *ΔnetOD*, calculated by subtracting change in optical density of the control (un-irradiated) film piece from the irradiated one, in accordance to radiochromic film dosimetry protocol [7]. Since the response of radiochromic film is not linear, to reconstruct the per cent depth dose curve, we used a linearization method described by Devic et al. [8]. Beam output was calibrated using IAEA TRS-398 reference dosimetry protocol with calibrated chamber in water. Films were calibrated in terms of dose to water by exposing calibration film pieces within a solid water phantom at depth of 3 mm. This depth was chosen in accordance to the measurement results of PDD shown in Fig. 2.

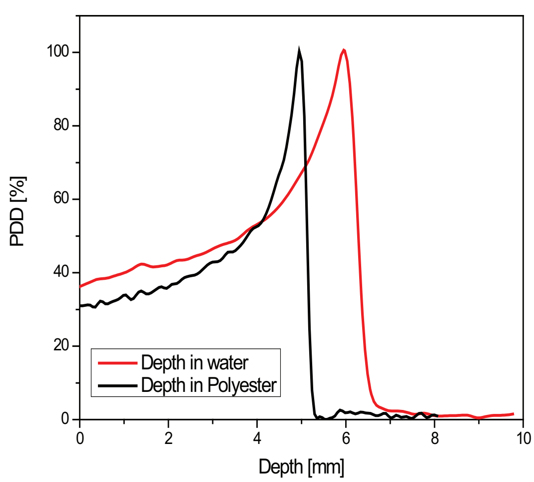

Figure 2: Per cent depth dose curve for 26 MeV proton beam. Black line represents relative dose as a function of physical density of film pieces, for the red line depths were scaled to density of water.

EBT3 films were irradiated to doses of up to 10 Gy with both 4 MV photon and 26.5 MeV proton beams, while pieces of the HDV2 radiochromic films were irradiated to doses of up to 128 Gy proton beam. Figure 3 illustrates the water phantom used to measure the output of the proton beam at a distance 70 cm from the beam exit, where a 2 mm diameter aluminium collimator was placed. In the same figure, we indicate the use of a radiochromic film piece that was used for the alignment of the center of the chamber with the central axis of the proton beam.

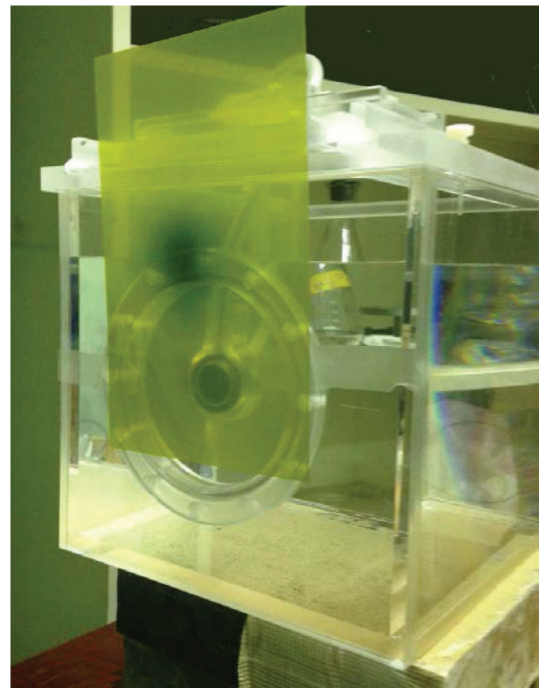

Figure 3: Water phantom used reference dose measurements based on TRS 398 IAEA protocol.

Irradiated pieces of the EBT3 films were tested for activation using Germanium detector. Their energy spectra were measured over a period of 40 minutes. Decay curve was measured using the Fluke 451 Ion Chamber Survey Meter. Reading were taken 20 sec for the first 5 minutes, then every 2 minutes up to 20 minutes and finally every 5 minutes up to 40 minutes post irradiation.

RESULTS

Figure 2 represents the per cent depth dose curve for the 26 MeV proton beam measured with HDV2 model GAFCHROMICTM film. The blue line represent depth dose curve where depth correspond to the physical thickness of the film pieces. The red depth dose curve is replotted blue curve but now with points corresponding to water equivalent depth, which was calculated as a physical thickness of the film piece scaled by physical density of Polyester, which 1.36 g/cm^3. As shown in Fig. 4, the EBT3 GAFCHROMIC™ film model response was 3 times higher for protons than photons. On the other hand, when irradiated in proton beam the EBT3 film model was 24 times more sensitive than HDV2 films. At the time of HDV2 model film calibration, the output at the depth of 3 mm inside Solid Water phantom was estimated to be 1.61 Gy/sec based on TRS-398 reference dosimetry protocol.

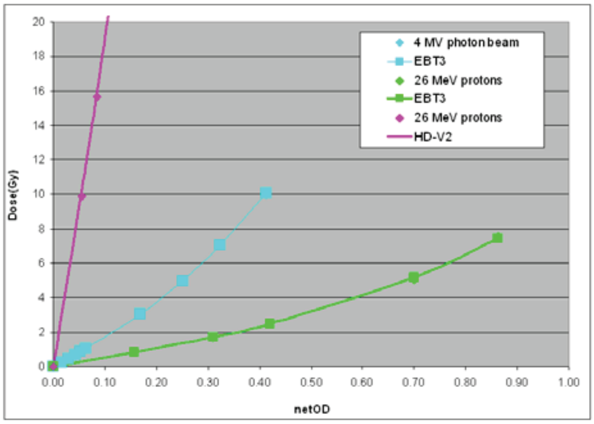

Figure 4: Calibration curves for EBT3 film irradiated in 26 MeV proton (green) and 4 MV photon (blue) beam qualities, and for HDV2 film irradiated in 26 MeV proton (red).

For the EBT3 film model, few proton-activated processes were identified resulting in short-lived radioisotopes (Fig. 5). The proton beam impinging on film was interacting with oxygen and carbon to create positron emitters ^{15}O, ^{13}N, and ^{11} C. Nuclear spectrum (Fig. 6) clearly indicated the existence of a single- and double escape 511 keV peaks, as well as the backscatter peak at 171 keV. We also observed a combination of the backscatter and 511 keV single-escape peak at 682 keV. However, the activity level of the isotopes produced was quite low, being 220 µSv/hr at 6 minutes after exposure to proton beam.

CONCLUSIONS

For low energy protons the EBT3 model GAFCHROMIC^{TM} films can be used for dose measurements of up to 10 Gy using a green colour channel of the scanned images, while the red colour channel of the HDV2 model GAFCHROMIC^{TM} films are better suited for dose measurements at much higher doses.

At very high dose rates, expected for proton beams created by cyclotrons, there is a possibility of proton activation processes that will result in fairly low activities of short-lived radioisotopes.

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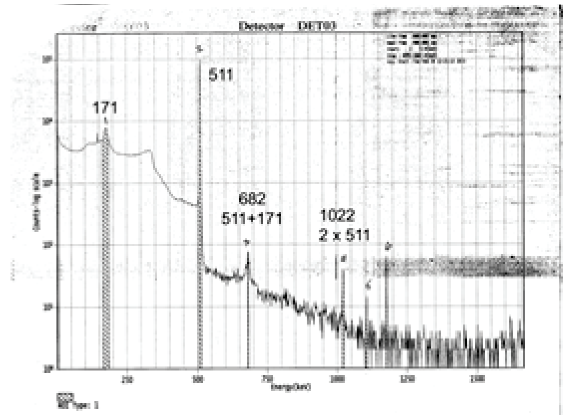

Figure 5: Decay curve consisting of 3 exponential components with half-lives corresponding to 15O, 13N, and 11C.

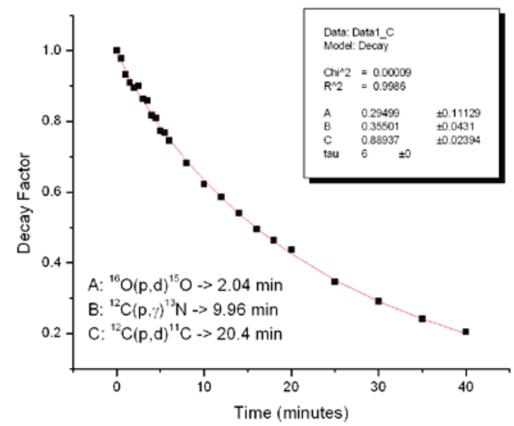

Figure 6: Nuclear spectrum from proton activated EBT3 model GAFCHROMIC^{TM} film.

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