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Original article

Energy dependence of radiochromic dosimetry films for use in radiotherapy verification

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ARTICLE INFO

Article history:
Received 13 July 2009
Received in revised form
17 February 2010
Accepted 22 February 2010

Keywords:
Radiochromic films
Quality assurance
Film dosimetry

ABSTRACT

Aim: The purpose of the study was to examine the energy dependence of Gafchromic EBT radiochromic dosimetry films, in order to assess their potential use in intensity-modulated radiotherapy (IMRT) verifications.

Materials and methods: The film samples were irradiated with doses from 0.1 to 12 Gy using photon beams from the energy range 1.25 MeV to 25 MV and the film response was measured using a flat-bed scanner. The samples were scanned and the film responses for different beam energies were compared.

Results: A high uncertainty in readout of the film response was observed for samples irradiated with doses lower than 1 Gy. The relative difference exceeds 20% for doses lower than 1 Gy while for doses over 1 Gy the measured film response differs by less than 5% for the whole examined energy range. The achieved uncertainty of the experimental procedure does not reveal any energy dependence of Gafchromic EBT film response in the investigated energy range.

Conclusions: Gafchromic EBT film does not show any energy dependence in the conditions typical for IMRT but the doses measured for pre-treatment plan verifications should exceed 1 Gy.

1. Background

The use of radiation fields modulated by dynamic multileaf collimators (dMLC) is a current practice in modern radiotherapy. Intensity-modulated radiation therapy (IMRT) and intensity-modulated radiosurgery (IMRS) are examples where dMLC is commonly used. Also the Tomotherapy modality of delivering IMRT is becoming more and more popular. The newest proposition is volumetric modulated arc therapy

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1507-1367/$ – see front matter
doi:10.1016/j.rpor.2010.02.003

(VMAT), where the dMLC movement is associated with accelerator gantry motion. These new technological possibilities of highly conformal radiotherapy allow very high dose gradients between the target and organs at risk to be achieved. The highly modulated dose distributions create a higher risk of unexpected irradiation of organs at risk with a high dose, or target underdosage, for example due to geometric uncertainties of the pre-treatment patient setup or caused by organ motion. The hazard of healthy tissue complications due to differences between the planned and delivered dose distributions creates a need for precise dosimetry verification of the delivered dose. The role of dosimetry films in the verification of IMRT is still important.[1] Compared with other 2D detectors, films offer very good spatial resolution and human-readable hard copies of the plane dose distributions. The limited thickness allows for sandwiching the film detector between slabs of solid phantoms in various geometries. The films can be read on many types of scanners or densitometers, etc. The most popular radiographic films are built as a thin and flexible base coated with gelatine emulsion containing a metal halide such as silver bromide or silver chloride radiosensitive crystals.[2] Due to the high atomic number of the radiosensitive components the radiographic films are radiation energy dependent. In the case of phantom dosimetry the films over-respond relative to the adjacent tissue equivalent material due to higher probability for photoelectric interactions of photons, particularly of energy below 400 keV, with the silver atoms in the emulsion.[3]

In recent years new types of films and film-like dosimetry detectors have appeared. Examples are radiochromic films and thermoluminescent detector (TLD) foils. Radiochromic films are based on an organic pentacosa-10,12-diynoic acid (PCDA) active component.[4] The PCDA monomer immediately polymerizes when irradiated by high-energy photon beams and becomes blue proportionally to the absorbed dose. Radiochromic films are near tissue equivalent and offer high spatial resolution, making them suitable for measurements of dose distributions with high dose gradients. Radiochromic films are practically insensitive to room light and do not need further processing. However, they should be kept away from UV radiation present in sunlight or emitted from glow-tube lighting.

2. Aim

In this paper a new type of radiochromic film is evaluated for use in phantom dosimetry for verification of the planned dose distribution in IMRT. The main goal was to determine the expected lack of energy dependence due to the atomic composition of Gafchromic films similar to the typical tissue equivalent phantom materials.

3. Materials and methods

3.1. *Dosimetric film types*

The example of radiochromic type films – GafChromic EBT (International Specialty Products, Wayne, NJ, USA) – has been designed for measurements of the absorbed dose from high-energy (above 1 MV) photons employed in intensity-modulated radiation therapy (IMRT). GafChromic EBT (external beam therapy) consists of two active layers, each 17 μm thick, bound by a surface layer of a thickness of 6 μm and sandwiched between 97 μm clear polyester foils. The mean atomic composition of the EBT film is C (42.3%), H (39.7%), O (16.2%), N (1.1%), Li (0.3%) and Cl (0.3%).[5] In this study, the film batch numbers are 34351-05I.

3.2. *Measuring setup*

EBT films of original size 8 in. × 10 in. were cut into rectangular pieces of size 4 cm × 5 cm, keeping the original orientation of a longer side. The samples were packed in light-protecting envelopes and sent by post in an outer standard envelope for irradiation. To reduce the ambient light effects the films were only removed from their light-protecting envelope during irradiation and readout.[6] The samples were irradiated in Warsaw, Gliwice, Vienna and Wrocław radiotherapy centres with beams from the energy range 1.25 MeV to 25 MV. During preparation and positioning the films were protected from daylight and light from the glow-tube lamp, to avoid UV radiation. The films were handled in accordance with the recommendations outlined in the AAPM TG-55 report.[7]

Each film sample was sandwiched between the 20 cm × 20 cm × 5 cm slabs of a SolidWater type 457 (Gammex RMI, WI, USA) or RW3 (PTW-Freiburg, Germany) water equivalent phantom parallel to the largest surface of the slab and irradiated. The films were exposed to doses of 10, 20, 50, 100, 200, 400, 600, 800, 1000 and in a few cases to 1200 cGy. The films were placed at 100 cm distance from the beam source at 10 cm depth. Also pieces of the phantom material of thickness dependent on the beam energy were placed below the film, to provide sufficient backscatter. The beam axis was pointing at the geometric centre of the film sample. The following beams were used in the study: Varian (Varian Medical Systems, Palo Alto, CA, USA) linear accelerators, type “Clinac 2300 C/D” (6 and 15 MV photons in Warsaw), type “Clinac 23 EX” (6 and 20 MV photons in Gliwice), type 2100 C/D (4 and 10 MV photons in Wrocław) and Elekta (ELEKTA Oncology Systems, Crawley, UK) linear accelerator, type “Sli precise” (25 MV photons in Vienna). The Cobalt-60 beam was available from a “Theratron 780E” unit (MDS Nordion, Ottawa, Canada) in Warsaw. After irradiation the samples were sent back to Warsaw and read out. The irradiated EBT films were stored in a refrigerator at a temperature of 4 °C (39 °F), to minimize the long-term changes of optical density.[8] A day before scanning they were taken out of the refrigerator and kept at standard laboratory temperature and humidity in light-proof envelopes.

3.3. *Digitizing*

The films were digitized with an EPSON Perfection V750 (Seiko Epson Corporation, Nagano, Japan) desktop flat-bed scanner. Anti-reflective lens coatings as well as a high-reflection mirror were originally built in the scanner. The Epson V750 digitized reflective or transparent samples. The light in the scanner was generated with two tube-shape Xe-gas fluorescent lamps with cold cathode. In the transparency mode the lamp placed in the top part of the device moved over film samples lying on the scanner glass. In the reflective mode the lamp placed in the bottom part of the scanner illuminated the underside surface of samples. The images were digitized with photoelectric light sensors built in the charge-coupled device (CCD) linear array placed under the glass. The scanning software EpsonScan provided with the scanner allowed images to be acquired in 48-bit colour mode, e.g., 16 bits per each colour channel: red, green and blue (RGB) or in 16-bit greyscale mode. The film samples were digitized at least 24 h after irradiation, to achieve stable post-irradiation colouration.[7,9] The scanner was turned on 15 min before measurements were made. All automatic image adjustments and filters available in the scanning software were disabled during acquisition of the digital images.[10] This allowed the same post-processing conditions to be preserved for all digitized images. For each beam energy the film samples irradiated with different doses were put together on the scanning glass and

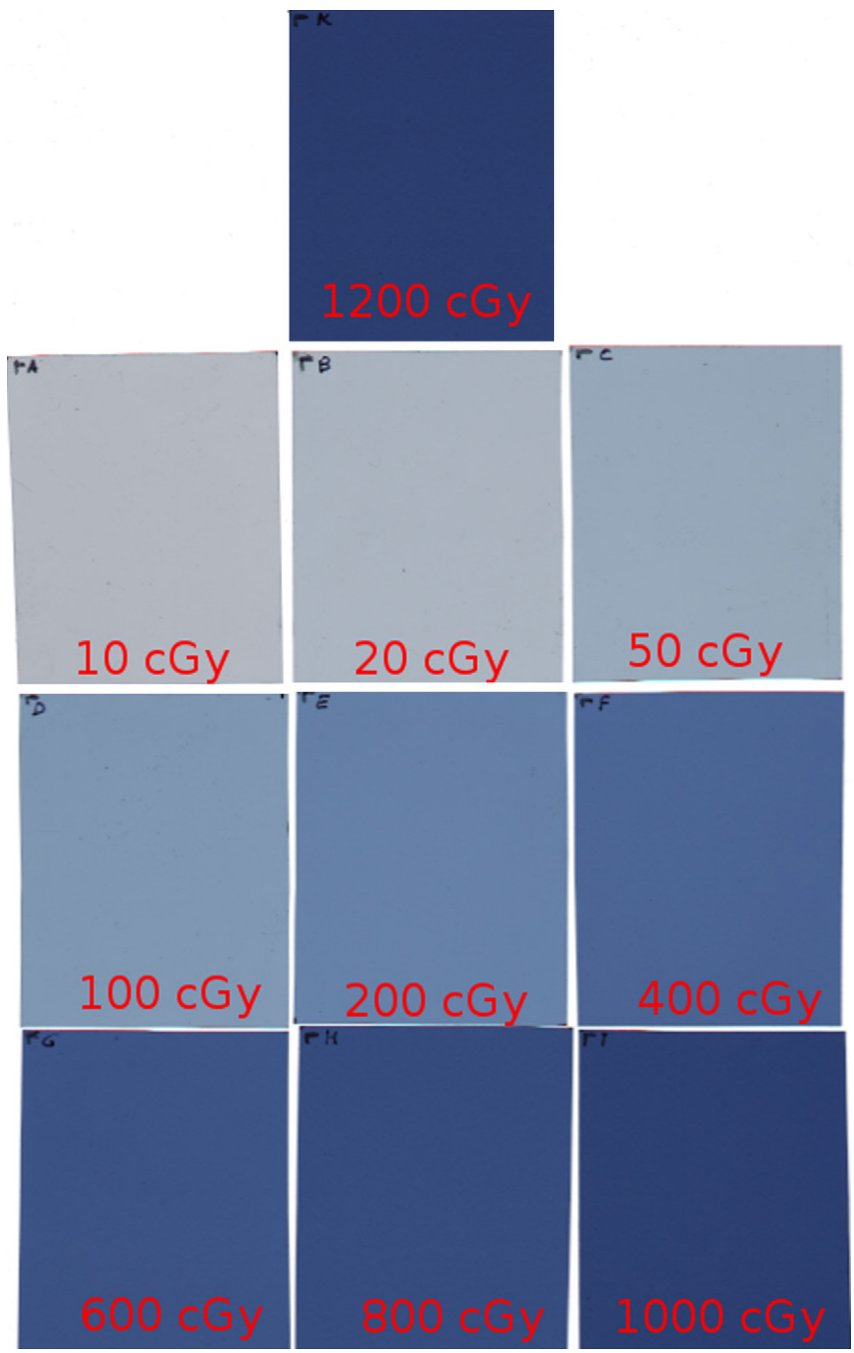

Fig. 1 – Example of the digital image of film samples irradiated with different doses. The film samples were put together on the scanning glass and subsequently digitized giving a series of five digital images. Positions and the orientation of the film samples irradiated with the same dose remained unchanged over all beam energies.

read in a session of five successive scans after three successive preview scans. The preview scans provided warming-up of the glass and the film samples to a stable and uniform level of temperature which minimizes the effect of reported temperature dependence of the film response.[11] The positions of the samples with the same dose were fixed through all investigated beam energies. This was set in order to avoid the influence of non-uniform response of the flat-bed scanners over the surface of the scanning glass[12] on the results of comparison of the film response for different beam qualities. Fig. 1 presents the positions of the film samples on the glass for a chosen energy. Before each readout session the scanner with the films placed on the glass was warmed up with three successive scans. The images were acquired at a resolution of 75 dpi or 0.3387 mm per pixel as 48-bit RGB uncompressed tagged image file format (TIFF) binary files. Also an unexposed film was scanned for background correction. The commercially available FilmQA software (3Cognition LLC, Great Neck, NY, USA) was used for processing of the irradiated films. The software allowed for the colour separation of scanned images and processing of a chosen channel (red, green or blue). The software contained features for correcting the effects of light scattering in CCD scanners. The effect appears as a non-uniform axial sensitivity perpendicular to the scanning direction.[13] The software allowed for defining a region of interest (ROI) and reading the mean pixel value (PV) and the standard deviation of PV inside the ROI. The defined ROI could be moved over the remaining part of the image, allowing for subsequent measurements of adjacent film samples. In the readout procedure each binary file containing an image of the set of film samples was imported. The colour separation was done and only the red channel was chosen for further examination because irradiated EBT films have two absorption peaks located at 636 and 585 nm.[14] The ROI of size 49.89 mm × 40.32 mm was defined and centred in the middle part of the first sample around the beam axis passing point. The measurement results for the first sample were recorded and the ROI was moved to the next sample. The procedure was repeated for all samples from the image. The mean from five measurement results corresponding to five successive scans was taken for each measurement point. From each series of digital images corresponding to each investigated beam energy a film response to dose dependence was obtained.

4. Results

In Fig. 2, the film responses for all delivered doses are presented for several beams investigated in the study. For each dose the mean PV from 3 of 5 scans was taken as the film response result. The two most wander results were neglected. Fig. 3 presents the standard deviation from three scans for each investigated dose and beam energy. A high uncertainty in readout of PV was observed for doses below 1 Gy. In Figs. 4 and 5, the normalized PVs are presented for two dose ranges, 0–1200 and 100–1200 cGy, respectively. The data were normalized using the mean PV from all irradiated films for each dose. The relative uncertainty exceeds 20% for doses below 1 Gy while in the dose range over 1 Gy

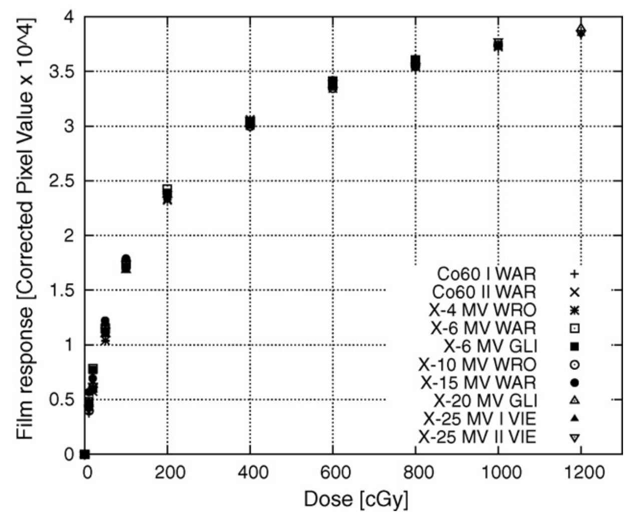

Fig. 2 – The response of the film samples irradiated with different doses for the beam energy range 1.25 MeV to 25 MV. The PVs were corrected using the background of an unexposed film.

the measured film responses differ by less than 5% for the whole examined energy range. Figs. 6–8 present examples of reproducibility of the experiment (irradiation and readout) at the same place. The pairs of presented data were obtained from two series of film samples irradiated in Warsaw with a Co60 beam (Figs. 6 and 7) and two series irradiated with a 25 MV beam in Vienna (Fig. 8), both read in Warsaw. The presented film responses were normalized by the mean PV calculated for each pair of films irradiated with different doses. The error bars represent the standard deviation for each scanning series (see Fig. 3) normalized by the mean PV for each pair of films. Figs. 9 and 10 present a com-

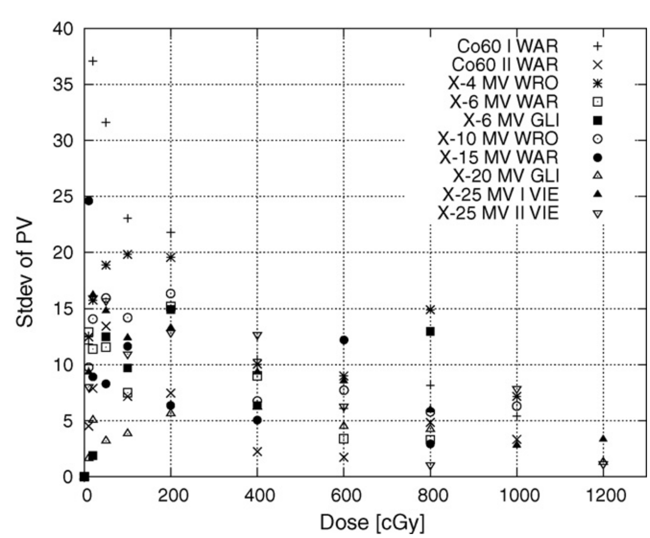

Fig. 3 – Standard deviation of measured PV against the delivered dose for different energy beams. The scans were made with an EPSON V750 scanner.

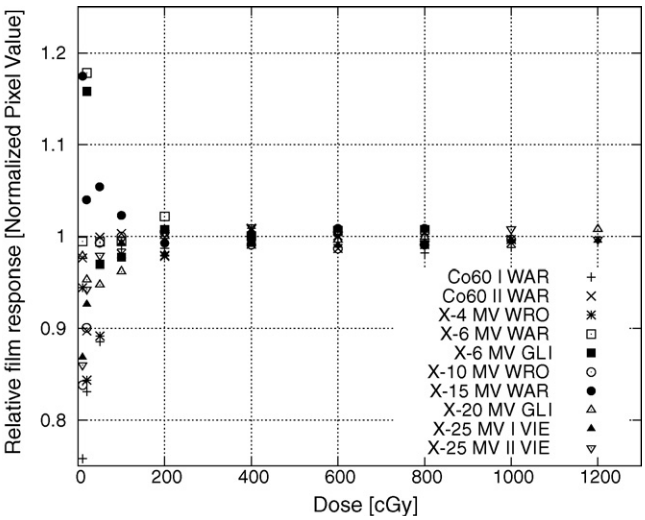

Fig. 4 – The relative response of the film samples. The normalized PV for each dose was obtained by dividing the film response by the mean PV for all beam energies.

parison of the film response as a function of energy at the same place: Warsaw 1.25 MeV, 6 MV, 15 MV and Gliwice 6 and 20 MV.

5. Discussion

The high uncertainty in readout of PV for doses below 1 Gy seen in Figs. 3 and 4 is probably due to the low signal to noise ratio of the scanner for materials with low optical densities. In general, radiochromic films show a lower response than radiographic films. Also the non-uniform distribution of the active component over the surface of the film and the imperfect contact between the film surface and the scanner glass may affect the readout results. The mentioned effects are less pronounced for films irradiated with higher doses. Nevertheless, the values of standard deviation being the estimate of reproducibility of the scanner are very low in comparison to

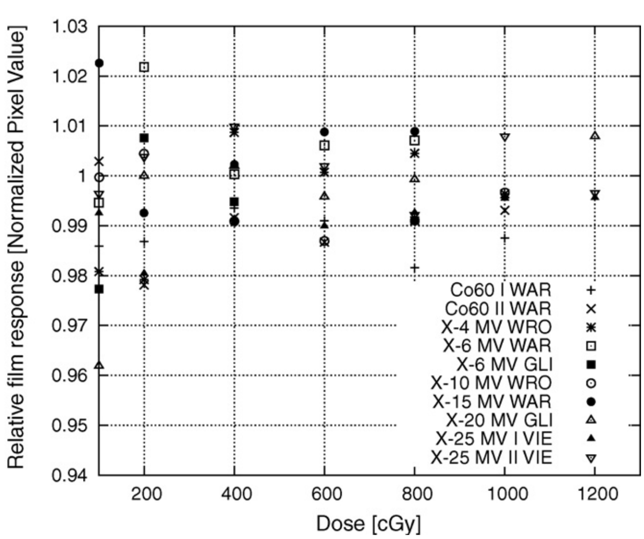

Fig. 5 – The relative response of the film samples for doses exceeding 1 Gy. The normalized PV for each dose was obtained by dividing the film response by the mean PV for all beam energies.

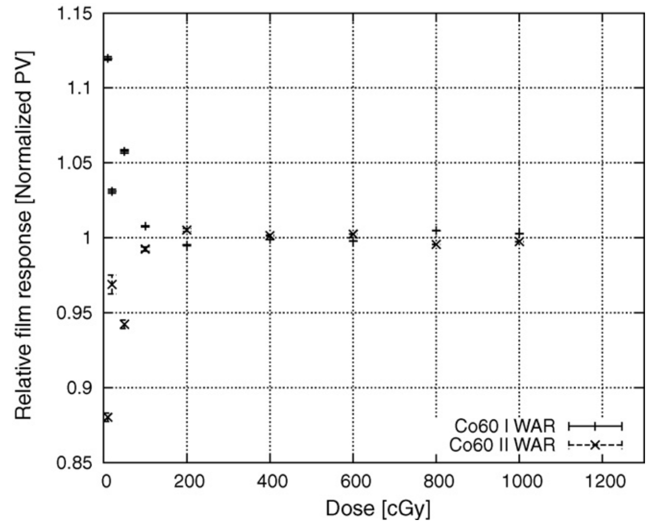

Fig. 6 – The film responses obtained from two series of film samples irradiated in Warsaw with a Co60 beam. The data were normalized by the mean PV calculated for each pair of films irradiated with different doses. The error bars represent the standard deviation for each scanning series normalized by the mean PV for each pair of films.

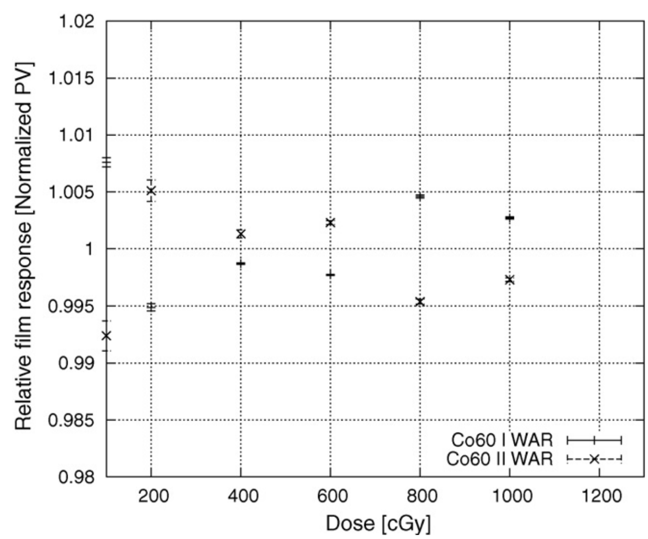

Fig. 7 – The film responses for doses exceeding 1 Gy obtained from two series of film samples irradiated in Warsaw with a Co60 beam. The data were normalized by the mean PV calculated for each pair of films irradiated with different doses. The error bars represent the standard deviation for each scanning series normalized by the mean PV for each pair of films.

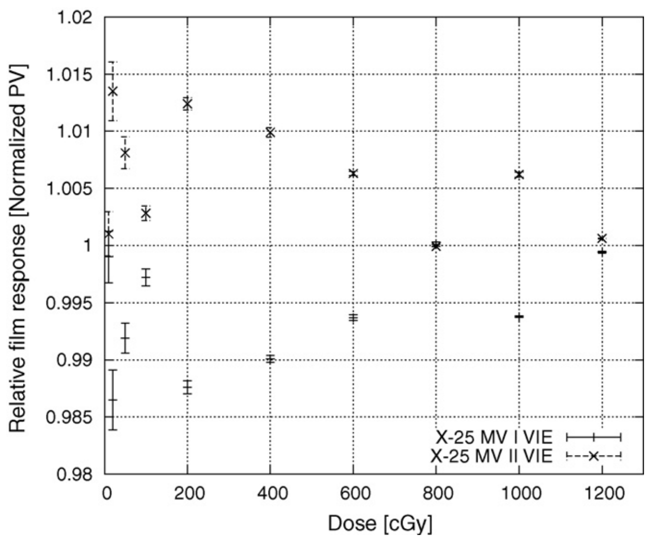

Fig. 8 – The film responses obtained from two series of film samples irradiated with a 25 MV beam in Vienna. The data were normalized by the mean PV calculated for each pair of films irradiated with different doses. The error bars represent the standard deviation for each scanning series normalized by the mean PV for each pair of films.

the measured film response (see Figs. 6–10). The reproducibility of the experiment at the same place with the same energy is within the range of 3% for doses exceeding 1 Gy. Also comparison of the film response as a function of energy for samples irradiated at the same place shows that the level of uncertainty is lower than 5%.

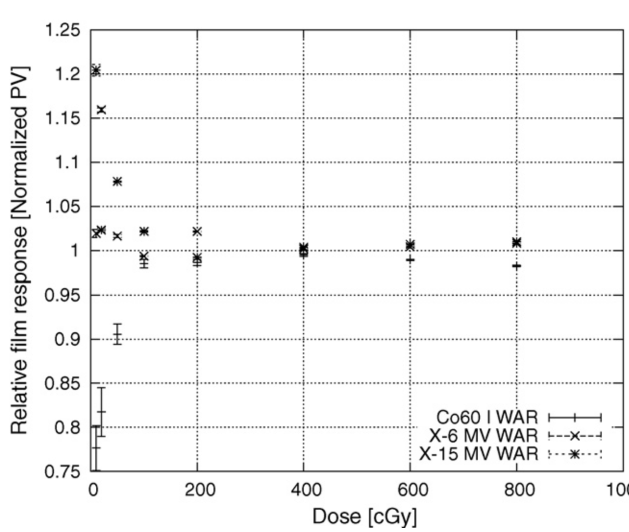

Fig. 9 – Comparison of the film response as a function of energy for films irradiated in Warsaw with 1.25 MeV, 6 MV and 15 MV beams.

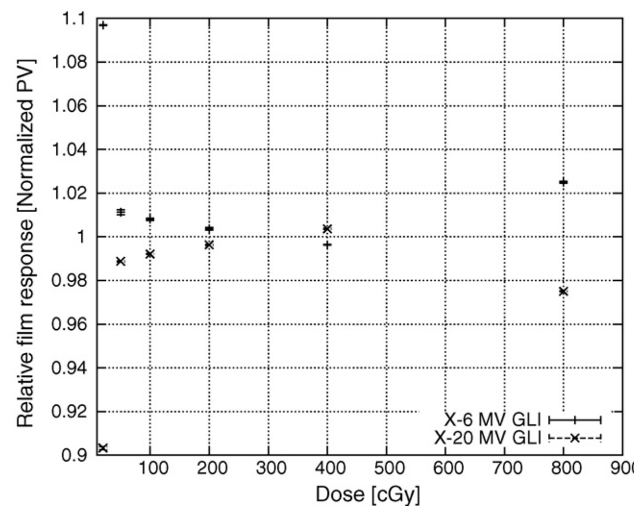

Fig. 10 – Comparison of the film response as a function of energy for films irradiated in Gliwice with 6 and 20 MV beams.

6. Conclusions

The examination of Gafchromic EBT films does not show energy dependence for the investigated beam energy range and for the achieved 5% precision of the measuring procedure. However, measurements of doses in the range below 1 Gy with Gafchromic EBT films demand special attention. If EBT films are used in pre-treatment dosimetric verifications of IMRT plans, the verified doses should exceed 1 Gy.

Acknowledgement

The work was supported by the Polish Ministry of Science and Higher Education—project no. R13 04 02.

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