REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 25 (2020) 60–63

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Technical note

Energy and dose dependence of GafChromic EBT3-V3 film across a wide energy range

Sarah Bassi[*], **Donal Cummins**, **Patrick McCavana**

St. Luke's Radiation Oncology Network (SRLON), Highfield Road, Rathgar, Dublin, Ireland

ARTICLE INFO

Article history:
Received 13 March 2019
Received in revised form
2 August 2019
Accepted 6 December 2019
Available online 9 December 2019

Keywords:
GafChromic EBT3-V3
Dosimetry
Energy dependence
Dose dependence
IPEM standard
DIN6809-4 standard

ABSTRACT

Aim: To determine the energy and dose dependence of GafChromic EBT3-V3 film over an energy range 0.2 mm Al HVL to 6 MV.

Background: The decay scheme of a brachytherapy source may be complex and the spectrum of energy can be wide. LiF TLDs are the golden standard recommended for dosimetric measures in brachytherapy, for their energy independence, but TLDs could be not available in some centres. An alternative way to perform dose measurements is to use GafChromic films, but they show energy dependence.

Methods and materials: Films have been irradiated at increasing dose with three different beams: 6 MV beam, TPR20, 10 = (0.684 ± 0.01), HVL = (2.00 ± 0.01)mmAl and HVL = (0.20 ± 0.01)mmAl. Calibration curves were generated using the same dose range (0cGy to 850cGy) for the three energies. Using the 6 MV calibration curve as reference, the film response in terms of net optical density (OD) was evaluated.

Results: The difference in the calibration curve obtained by irradiating the film with 6 MV and 2 mm Al HVL energy beams is less than 3 %, within the calibration uncertainty, in the dose range 500-850cGy. The OD of EBT3-V3 film is significantly lower at 0.2 mmAl HVL compared to 6 MV, showing differences up to 25 %.

Conclusion: Within the range 6 MV-2 mm Al HVL and dose higher than 500cGy, GafChromic EBT3-V3 films are energy independent. In this dose range, films can be calibrated in a simple geometry, using a 6 MV Linac beam, and can be used for brachytherapy sources dose measures. The use of EBT3 films can be extended to reference dosimetry in Ir-192 clinical brachytherapy.

1. Background

The energy of photon beams used in radiotherapy varies widely. Typical brachytherapy sources (as Ir-192 or Pd-103) have gamma energy ranges within 0.1–1.1 MeV.[1] Also in external beam treatments, the range is wide and includes low energies, such as 50 kV of intra-operative radiation therapy (IORT), up to 10 MV Linac produced beams. AAPM TG-43[1] highly recommends the use of LiF TLDs detectors for brachytherapy sources, for their low energy dependence. Nevertheless, the use of TLDs can be time-consuming, several uncertainties can arise from the TLD positioning and TLDs could be not available in some centres.

---

[*] Corresponding author.
E-mail addresses: Sarah.Bassi@asuiud.sanita.fvg.it (S. Bassi), Donal.Cummins@slh.ie (D. Cummins), Patrick.McCavana@slh.ie (P. McCavana).

https://doi.org/10.1016/j.rpor.2019.12.007

Ashland Specialty Ingredients (Bridgewater, NJ) manufactures a variety of radiochromic films, known commercially as GafChromic films, for a range of radiotherapy and diagnostic applications. EBT3-V3 film, the third generation of the External Beam Therapy line commercially available from August 2013, contains an active layer that is relatively water equivalent. This new generation of film is composed of C (51.1 %), O (32.8 %), H (8.8 %), Al (6.7 %) and Li (0.6), showing an effective atomic number of $Z_{eff} = 7.26$, close to water $Z_{eff} = 7.42$.[2] Compared to TLD, films are fast to process and error positioning is much lower. These features make the films attractive for dose measurements with brachytherapy sources. Nevertheless, measurements of the film calibration curve with the brachytherapy sources can be challenging due to the source high gradient of dose and the positioning uncertainties of the source relative to the film. Calibrating a film on a linac at an MV energy in a standard square field geometry is simple and avoids many of the positioning uncertainties. However, a question remains as to how valid a film calibrated in 6 MV been linac is when applied to brachytherapy measurements.

The photoelectric effect, that has a cubic variation with the effective atomic number, dominates photon attenuation up to energy of 30 keV in water equivalent materials[9] and affects film dose measurements. Small component of the photoelectric effect is still active and above 30 kV may affect the film dose measurements.

Brown et al.[3] have investigated the energy dependence with monochromatic beams and a previous generation of EBT3 films. They found a weak energy dependence over a range 25 keV – 4 MV. Hammer et al.[2] have investigated the dosimetric intrinsic energy response of GafChromic films on 15 beam qualities within the 500–7002 mGy range and suggested energy correction factors. Due to the wide energy spectrum of a brachytherapy source, these factors are not easy to apply in practice.

2. Aim

The aim of this work is to investigate over which range the film is energy and dose independent, in dose range 50–850cGy. The practical benefit of selecting a range of energy independence for GafChromic films is to calibrate them in a simple geometry and to use them for HDR brachytherapy sources dose measurements, without the energy correction factors.

In order to understand at which energies the film calibration obtained with the Linac irradiation is still valid, EBT3-V3 is investigated in the range 0.2 mmAl HVL - 6 MV, with polychromatic beams.

3. Methods and materials

Three dose response curves at three different beam energies were obtained from the same GafChromic EBT3 film box. For each calibration, eleven $5 \times 5\,\text{cm}^2$ pieces of the film were cut from a single sheet with a small marker on each piece indicating the orientation of the original. One piece of the film was not irradiated to provide the background of the OD. The pieces of the film were irradiated at increasing dose by: 6 MV beam ($TPR_{10}^{20} = 0.684 \pm 0.01$) generated by an Elekta Precise Linac; $HVL = 2.00 \pm 0.01$ mm Al beam and very-low-energy beam ($HVL = 0.20 \pm 0.01$ mm Al) both produced by a Gulmay Orthovoltage unit.

The Elekta unit was calibrated with PTW 30010 Farmer chamber (volume $0.6\,\text{cm}^3$), following the IPEM Code of Practice for MV beams (2003).[4] Films were placed at 5 cm depth in a water-equivalent phantom (WEP), 100 cm SSD, and were irradiated by a $10 \times 10\text{cm}^2$ 6 MV beam.

The 2 mmAl HVL beam was calibrated with PTW 30004 Farmer chamber (volume $0.6\,\text{cm}^3$), following the IPEM Code of Practice for kilovoltage beams[5] and the addendum.[6] Films were placed at the surface of a water tank and irradiated at 20 cm SSD, by a 6 cm diameter circular applicator.

The 0.2 mmAl HVL beam was calibrated with PTW TN34013A Ionization Chamber (volume $0.005\,\text{cm}^3$), following the German standard.[7] Films were placed at the surface of a water tank and irradiated at 30 cm SSD, by a 3 cm diameter circular applicator.

To ensure the calibration equivalence of the two different protocols, both were compared using a 2 mmAl HVL beam. The GafChromic EBT3 film was irradiated in water using a 6 cm circular applicator, 30 cm SSD, for IPEM protocol and a 3 cm circular applicator, 20 cm SSD, for the DIN6809-4 standard. The film OD versus dose were compared and the differences found were less than 3 % (coverage probability 95 %, k = 2), within the calibration uncertainties.

The protocol followed to scan the film is proposed by Ashland[11] triple channel analysis. All irradiated films were digitized using an Epson Expression 10000 XL scanner at 150dpi spatial resolution, at least 24 h after irradiation. The 12 films irradiated at the same energy were centred on the scanner bed, in a position easily reproducible to repeat the scan at each energy irradiation. The TIFF images were analysed using Film QA Pro software, red channel. The density colour and the standard deviation was measured using a circular ROI of 2 cm diameter centred in each piece of the film and, using Film QA Pro software, density colour was plotted versus dose.[8] The plot curve was extracted and the density colour converted in OD using the unexposed film. In order to check the stabilization of the colour, a second scan was performed after 72 h. The differences founded were within the standard deviation.

3.1. Uncertainties

The first and higher source of uncertainty is the systematic error associated with the calibration coefficient from

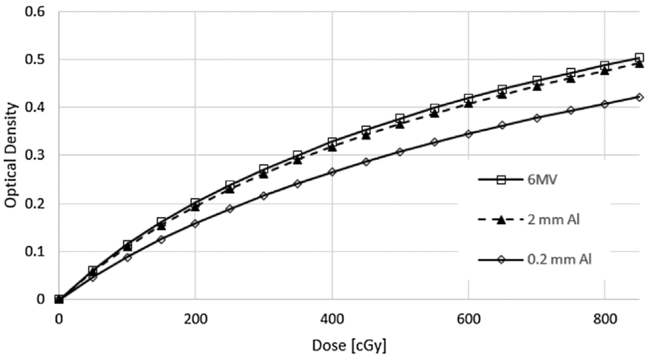


Fig. 1 – Optical density versus dose. The film was irradiated at 6 MV (squares), 2 mm Al HVL (triangles) and 0.2 mm Al HVL (rhombus).

the calibration certificates of NPL and PTW laboratories. The uncertainties are:

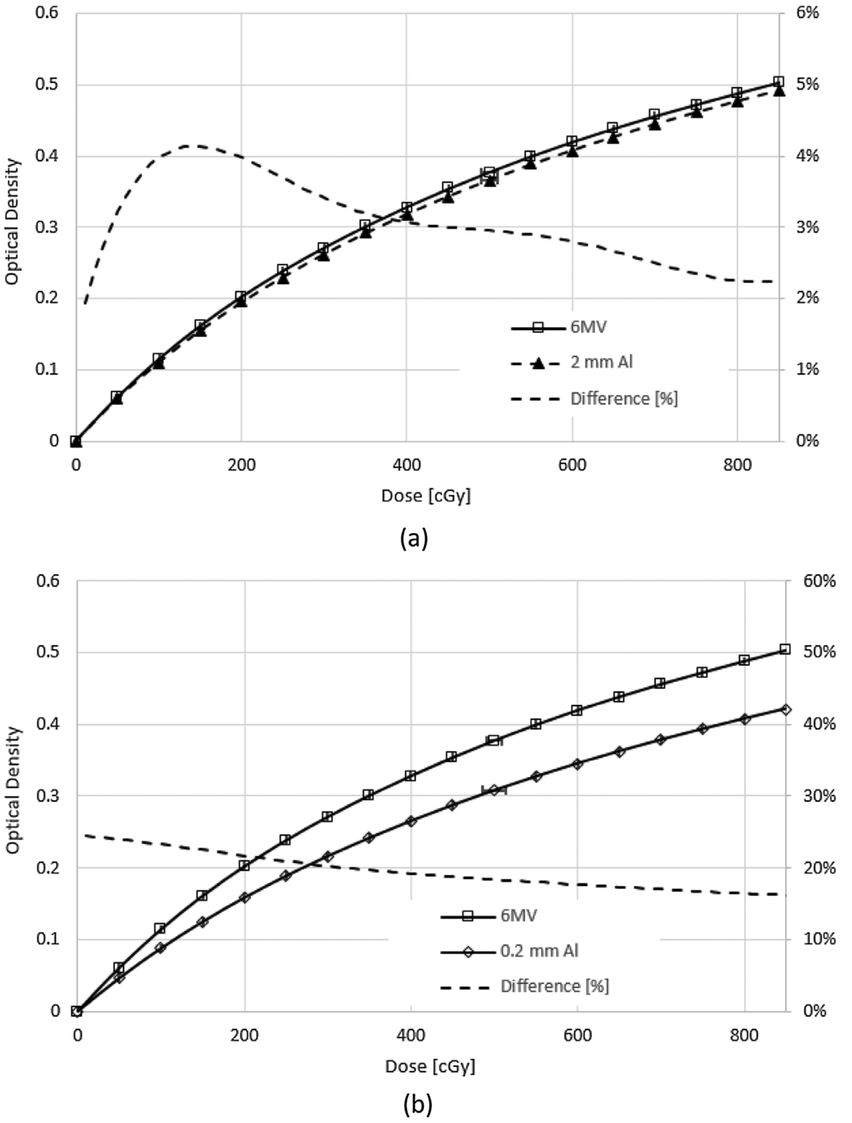
- 1.4 % by NPL certificate for 6 MV beam calibration;
- 1.2 % by NPL certificate for 2 mmAl HVL beam calibration;
- 2 % by PTW certificate for 2 mmAl HVL beam and 0.2 mm Al HVL beam.

The second source of uncertainty is the systematic error introduced by the inverse square law factor (ISL) used to calculate the output at the film position in respect to the chamber position. For the Linac beam and low-energy beam this uncertainty can be ignored because it is lower than 0.01 %, but for the 2 mmAl HVL beam Ortovoltage unit beams cannot be ignored for the short SSD. The ISL was measured using a PTW 34001 Roos Chamber with uncertainty in the position of 0.6 % (NPL) and 1.2 % (German protocol). The last two sources of uncertainty are the pressure and temperature correction factor (0.3 %) and the ion recombination factor (0.1 %). The film irradiation was done just after the devices calibration, checking the output reproducibility less than 0.1 %. The uncertainty in the OD was derived irradiated the films at 500 cGy, 6 MV four times and calculating the standard deviation of average. The uncertainty from the film noise is 1.3 %. The total dose uncertainty u_{D_w} is calculated using the error propagation theory[10]:

$$\frac{u_{D_w}}{D_w} = \sqrt{\frac{{u_{N_{D,w}}}^2}{N_{D,W}^2} + \frac{{u_{k_{ISL}}}^2}{k_{ILS}^2} + \frac{{u_{k_{TP}}}^2}{k_{TP}^2} + \frac{{u_{k_s}}^2}{k_s^2} + \frac{{u_{OD_{Film}}}^2}{OD_{Film}^2}}$$

where $N_{D,w}$ and $u_{N_{D,w}}$ are the calibration factor and the related uncertainty; k_{ISL} and $u_{k_{ISL}}$ are the inverse square law factor and the relative uncertainty; $k_{T,P}$ and $u_{k_{TP}}$ are the temperature and pressure calibration factor and the related uncertainty; k_s and u_{k_s} are the ion recombination correction factor and the related uncertainty; OD_{Film} and $u_{OD_{Film}}$ are the OD of the film and the related uncertainty.

The calculated total uncertainty is: 1.9 % for NPL 6 MV calibration, 1.9 % for NPL 2 mmAl HVL beam, 2.7 % from Ger-



(a)

(b)

Fig. 2 – Percentage difference of optical density versus dose irradiating the films with (4) 6 MV, square markers, and 2 mmAl HVL, triangles, and (b) 6 MV, square markers, and 0.2 mm Al HVL, rhombus. Dotted lines show the percentage difference of optical density. Error bars are reported at 500 cGy.

Table 1 – Comparison of optical density with beam energy increasing dose. The percentage difference is related to 6 MV energy irradiations.

Dose (cGy)	Optical density/% difference		
	6 MV	2 mm Al HVL	0.2 mmAl HVL
50	0.061	0.059 / 3.2 %	0.046 / 24 %
100	0.114	0.110 / 4.0 %	0.088 / 23 %
150	0.161	0.154 / 4.1 %	0.125 / 23 %
250	0.238	0.229 / 3.7 %	0.188 / 21 %
400	0.328	0.318 / 3.1 %	0.265 / 19 %
550	0.399	0.388 / 2.9 %	0.327 / 18 %
700	0.456	0.444 / 2.5 %	0.378 / 17 %
850	0.502	0.491 / 2.2 %	0.421 / 16 %

man Protocol 2 mmAl HVL beam, 2.5 % from German Protocol low-energy beam. This uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a coverage probability of approximately 95 %.

4. Results and discussion

Fig. 1 shows plots of the OD versus dose for 6 MV, 2 mmAl HVL and 0.2 mm Al HVL beams. The OD of the EBT3 film is significantly lower at 0.2 mmAl HVL compared to 6 MV. Higher differences are shown at lower dose and gradually decrease with increasing dose, with 24 % at 50 cGy and 16 % at 850cGy. OD is lower at 2 mmAl HVL compared to 6 MV but in the dose range 500-850cGy the differences are within the uncertainty of measures, with a confidence level of 95 %. In the range 50–500 cGy at 2 mmAl HVL there is a slightly increased difference of up to 4.1 %, outside the uncertainties of measurement of 3 %. However, for 0.2 mmAl HVL, this difference increases from 19 % to 24 % below 400 cGy.

Percentage difference of OD versus dose is shown in Fig. 2. Table 1 summarises the OD and the differences with beam energy increasing the dose.

In the investigated range of 2 mmAl HVL- 6 MV, a small OD variation was detected, that is within the uncertainty of measures in the dose range 500–850 cGy. The increasing difference in the OD as energy decreases can be attributed to photoelectric changes due to small differences in Zeff between EBT3-V3 and water.

5. Conclusions

An energy dependence of GafChromic EBT3-V3 is visible with low energy beam (0.2 mm Al HVL). Accordingly, film dosimetry for any photon beams in this energy range should be carefully used. Ir-192 has a very complex scheme of decay but it is within the range of 0.1–1.1 MeV. The standard treatment requests a dose per fraction in the range 500–700 cGy. In this dose range, films can be calibrated in a simple geometry, using a 6 MV Linac beam or an Orthovoltage beam, and can be used for brachytherapy sources dose measures, with 3 % uncertainty (k = 2). Under this circumstances, GafChromic EBT3 films can be suitable for dose measurements because in this range the OD shows a variation within uncertainty.

Pd-103 is a source used in low dose rate (LDR) brachytherapy and it has characteristic x-ray with mean energy of 20.7 keV,[1] where the films are energy dependent.

Literature shows,[2,3,12] studies of films used in many fields. Our study shows that the use of EBT3 Gafchromic films can be extended to reference dosimetry in Ir-192 clinical brachytherapy, at dose >5 Gy. The measurement results are associated with an overall uncertainty below 3 % (k = 2) and are dose-rate and energy independent.

Financial disclosure

All authors declare that they do not have any financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

Conflict of interest

They do not have any conflict of interest

REFERENCES

1. Rivard M, Coursey B, DeWerd L, et al. Update of the AAPM task group no. 43 report - a revised AAPM protocol for brachytherapy dose calculations. *Med Phys*. 2003;31(3):2004.
2. Hammer CG, Rosen BS, Fagerstrom JM. Experimental investigation of Garchromic EBT3 intrinsic energy dependence with kilovoltage x-rays, 137CS and 60Co. *Med Phys*. 2018;45(1):448–459.
3. Brown T, Hogstrom K, Alvarez D, Matthews K, Ham K, Dugas J. Dose-response curve of EBT, EBT2, and EBT3 radiochromic films to synchrotron-produced monochromatic x-ray beams. *Med Phys*. 2012;39(12):7412–7417.
4. Lillicrap S, Owen B, Williams J, Williams P. Code of Practice for high-energy photon therapy dosimetry based on the NPL absorbed dose calibration service. *Phys Med Biol*. 1990;35(10):1355–1360.
5. Klevenhagen SC, Aukett RJ, Harrison RM, Morettu C, Nahum AE, Rosser KE. *The IPEMB code of practice for the determination of absorbed dose for x-rays below 300 kV generating potential (0.035 mmAl – 4 mmCu HVL; 10-300 kV generating potential)*; 1996.
6. IPEM working party, Addendum to the IPEMB code of practice for the determination of absorbed dose for x-rays below 300 kV generating potential (0.035 mm Al – 4mm Cu HVL).
7. German Standard. *Application of X-rays with Tube Voltages between 10 and 100 kV in Radiotherapy and Soft tissue Diagnostics*; 1988.
8. Efficient Protocols for Accurate Radiochromic Film Calibration and Dosimetry (available at this URL: GafChromic).
9. Pope J. *Medical physics: Imaging*. Oxford: Heinemann; 1999.
10. Hughes I, Hase T. *Measurements and their uncertainties*. Oxford: Oxford University Press; 2011.
11. Documentation on GafChromic website: http://www.gafchromic.com/documents/Efficient%20Protocols%20for%20Calibration%20and%20Dosimetry.pdf (last visit 20/02/2019).
12. Devica Slobodan, Lianga Li Heng, Tomica Nada, et al. Dose measurements nearby low energy electronic brachytherapy sources using radiochromic film. *Phys Med*. 2019;64:40–44.