GAFCHROMIC FILM EBT3 CALIBRATION FOR QA IN RADIOTHERAPY

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Abstract

In modern radiotherapy, advanced dose distribution techniques are being widely implemented. The primary goal of these techniques is to deliver the maximum dose to the target area while minimizing exposure to nearby healthy tissues and organs at risk (OAR). Due to their complexity, these techniques demand rigorous dosimetry verification. In dynamic dose distribution, there are instances where the delivered dose may match the planned dose in some regions but different in others. As a result, verifying treatment plans involving intensive and dynamic dose distributions requires a method capable of measuring doses at multiple points simultaneously. Gafchromic films are among effective tools for measuring relative doses. In recent years, the use of gafchromic films has become more prevalent. These films offer the advantage of being self-developing, eliminating the need for chemical processing or darkroom conditions, making them an efficient option for dosimetry verification of advanced techniques in radiotherapy. In Albania the only radiotherapy center that use it, is the department of medical physics to American Hospital Tirana.

Key words: *gafchromic films EBT3, dosimetry, calibration curve.*

Përmbledhje

Në radioterapinë moderne, teknikat e avancuara të shpërndarjes së dozës po zbatohen gjerësisht. Qëllimi parësor i kësaj teknike është të japë dozën maksimale në zonën e synuar duke zvogëluar ekspozimin e indeve dhe organeve të shëndetshme në rrezik, pranë zonave të trajtimit (OAR). Për shkak të kompleksitetit të tyre, këto teknika kërkojnë verifikim rigoroz të dozimetrisë. Në shpërndarjen dinamike të dozës, ka raste kur doza e dhënë mund të përputhet me dozën e planifikuar në disa zona, por mund të ndryshojë në disa të tjera. Si rezultat, verifikimi i planeve të trajtimit të cilat përfshijnë shpërndarje intensive dhe dinamike të dozës kërkon një metodë të aftë për të matur dozat në disa pika njëkohësisht. Filmat gafkromik janë ndër mjetet më efektive për matjen e dozave relative. Vitet e fundit, përdorimi i filmave

gafkromik është bërë më i përhapur. Këto filma ofrojnë avantazhin e të qenit vetë-zhvillues, duke eliminuar nevojën për përpunim kimik ose kushte e dhomës së errët, duke i bërë ato një mundësi efikase për verifikimin dozimetrik të teknikave të avancuara në radioterapi. Në Shqipëri e vetmja qendër radioterapie që i përdor filmat gafkromik është departamenti i fizikës mjekësore pranë Spitalit Amerikan Tirane.

Fjalë kyçe: *film gafkromik EBT3, dosimetry, kurbe kalibrimi* .

Introduction

The Gafchromic EBT3 film is composed of an active laminate layer which is located between two polyester layers. Polyester surfaces make a strong product and allow the film to be submerged in water.

These layers contain microscopic silicon particles (less than 10 μm in diameter). Their purpose is to help model the formations of Newton's rings that can appear when two smooth layers merge. Newton's rings are artifacts that affect dosimetric measurements. The silicon particles on the surface of the EBT3 have a large gap between the film and the scanner glass to eliminate the formation of Newton's rings. The amount of silicon in the substrate is less than 1% and has no measurable effect on the dose delivered in the EBT3 film. Also, the EBT3 film has a symmetrical structure (D. Lewis and M F. Chan, 2015).

As the absorption spectrum of the active component of Gafchromic EBT3 peaks at 636 nm, sensitivity is maximized when measured in red light. This highly sensitive gafchromic film is designed to measure the absorbed dose of the high energy photons used in the complex treatment plan. The film is produced to measure doses above at least 30 Gy when using an RGB color scanner.

At doses below 10 Gy, the response in the red channel approaches saturation, so in the case of a single channel it is preferable to change the channel to green for these measurements. Although it is possible to extend measurements up to 50 Gy or more using the blue channel, this has not yet been observed. The film is designed to have a photon response that is roughly energy bound from 100 keV to the MeV limit. This is done by designing the atomic composition of the film.

Gafchromic EBT3 film is designed to be kept away from room lights. In this case the marker color makes the film 10 times less sensitive to room lights than the original EBT product. Exposing it to light rays should be avoided as the source wavelengths are UV to which the film can be very sensitive. Just a

few minutes of exposure to direct sunlight causes the film to noticeably darken.

The film should be stored in a dark room with an ambient temperature of 20^0-25^0 and away from sources of radiation. The best response will be when the relative humidity in the environment is below 50% and it is preferable that this humidity is controlled. If this difference goes from 20% to 60% it would be undesirable because the moisture content of the film can change and lead to noticeable differences in the scanner readings.

If a film has been stored in the refrigerator, it should be left out at room temperature before use. This is done to avoid the possibility of condensation of the cold open film in a warm moist environment.

The active layer in EBT3 is protected by two layers of polyester. The film is composed of a 27 μm thick active layer, and two 125 μm thick polyester layers at the two sides. Since the diffusion of water through polyester is extremely slow, the film can be submerged in water for short periods without damage. This happens because the sides of the film are not kissed and the water will go to the active layer. Diffusion is very slow and the film can remain immersed for several hours and only the active layer within a few millimeters of its sides will be affected. The affected area is very visible because it develops an opaque appearance while absorbing water. Dosimetry is not done in these areas.

Methodology

Calibration of a film is the first condition in the film dosimetric protocol. It is very important to establish the accuracy and continuity of dosimetric measurements and process evaluation. To make measurements on EBT 3 films it is necessary to characterize an average ratio between film dose and response when the film is exposed and measured by appropriate instruments. Many solutions to this process may seem simple, but there are a significant number of solutions to find the best approach.

The first problem in calibrating films is size. For economic reasons, the usual solution is to cut the film into small pieces, each of which will receive a dose of exposure. First, the area of each part must be large enough that the measurements are clear on the film. To compensate for what we cannot guarantee, the idea of using a "dye marker" pencil has been developed, allowing us to distinguish artifacts from the dose information on the film. For this to happen again small parts are needed to calibrate the film. There is

another reason why calibrating film with small parts is risky. Usually these parts have a side of the film. For example, if the relative humidity of the environment changes significantly (+/-25%) in a short period (<2-3 days), the active layer of the film parts may change until the film sheet equilibrates to the new environmental temperature. Very often dose calibration will be used to determine the dose in the advanced treatment plan at the center of the film sheet. It is reasonable that a calibration cannot be developed using small pieces of film from the sides of the sheet (Lewis D., Micke A., Yu X, Chan M, 2012).

Results

After preparing the EBT 3 film into small parts, we will start the calibration procedure. For this purpose, we have established some reference conditions. The following table shows the reference conditions, surface dose distance (SSD), field size (FS), temperature (T), pressure (P), energies (E), charge (Q) and dose (D) for which the calibration was made, figure 1, table1.

Table 1. Set-up calibration data

SSD (cm)	FS (cm^2)	T (C^o)	P (kPa)	E (MeV)	Q (nC)	D (cGy)
100	10 x10	20 ±2	100.98	6	11.66	16.04
				18	0.786	126

These reference conditions are dictated by following the standard linear accelerator calibration procedure according to the protocol of the International Atomic Energy Agency (IAEA) No. 398 as well as using ionization chambers of the type PTW Farmer 30010 with 0.6 cm^3 volume, designed for absolute photon and electron dosimetry with therapy dosimeters (IAEA 2000 TECDOC 398). The chamber is used for measurements in air, water or in solid state phantom material. The wall material is graphite with a protective acrylic cover, and the electrode is made of Al. The nominal photon energy range is from 30 kV to 50 MV, figure 1.

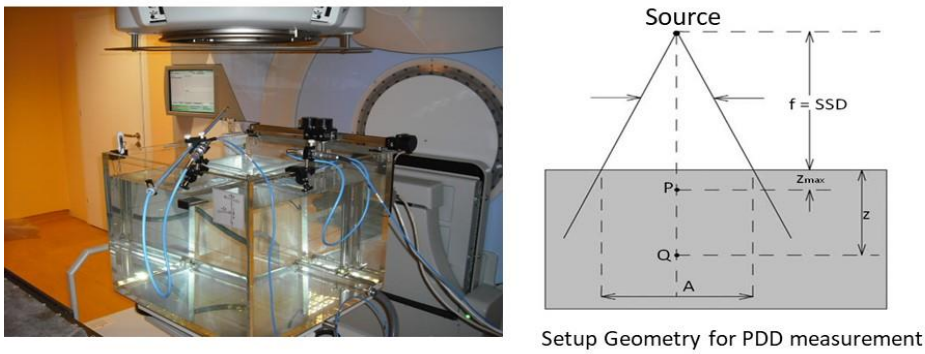

Figure 1: Setup geometry for PDD measurement and absolute dosimetry

In these conditions we will refer to the evaluation of absolute dosimetry measurements, performed with water phantoms at a depth reference, d_{ref}, of 10 cm as well as evaluating the percentual depth dose curves (PDD) for 6 and 18 MV energies.

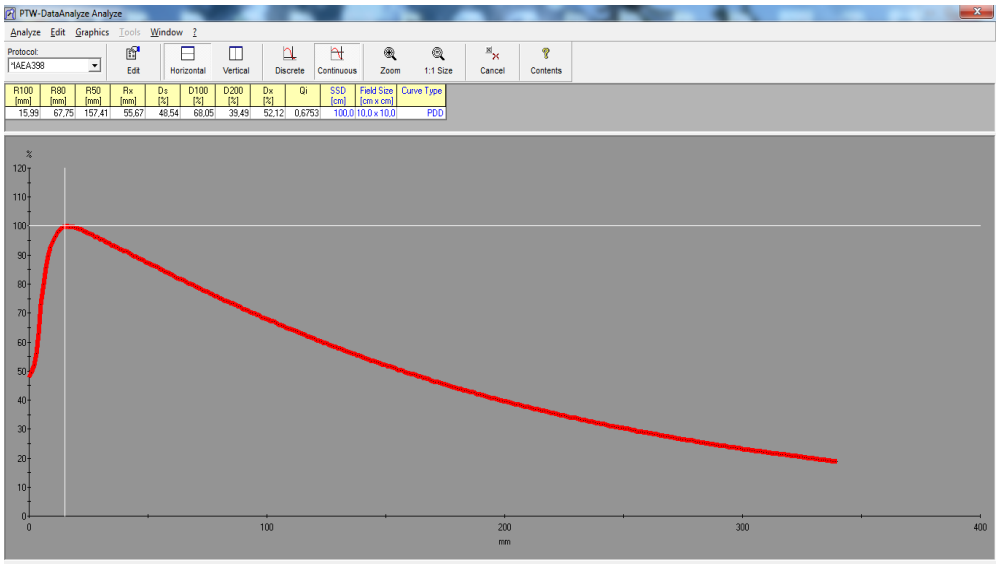

Figure 2: Depth dose percentage for 6 MeV energy for 10 x10 cm^2 field

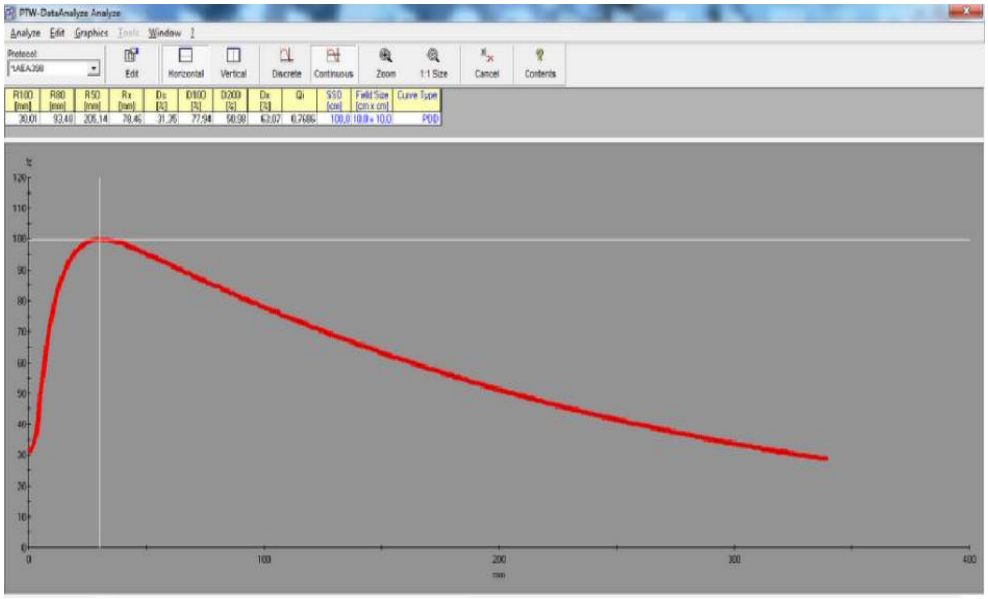

Figure 3: Depth dose percentage for 18 MeV energy for 10 x10 cm^2 field

Figure 2 shows the plot of Percent Depth Dose (PDD) for 6 MV energy. At the maximum depth (d_{max}), which is 1.6 cm for the water phantom and 1.36 cm for PMMA, the dose reaches its peak. Given that at a depth of 10 cm the dose is 1 Gy, which is 68% of the maximum dose, the dose at d_{max} is 1.47 Gy.

Figure 3 shows the plot of Percent Depth Dose (PDD) for 18 MeV energy, the depth to reach the maximum dose (d_{max}) is 3.0 cm for the water phantom and 2.55 cm for PMMA. At a depth of 10 cm, the dose is 0.9967 Gy, which is 78% of the maximum dose. Therefore, the dose at d_{max} is 1.279 Gy.

The calibration was performed using PMMA plates which also are used for the reference dosimetry of the linear accelerator.

Table 2: Doses for different energy and MU

MU	Dose (cGy) / 18 MV	Dose (cGy) / 6 MV
100	126	0.768
200	253	157
400	506	314
600	760	471
800	1013	628
1000	1267	786

The film was placed between these plates above the ionization chamber and irradiation was performed on the surface. The table 2 shows the energies and how many MUs were given to the six pieces of film. We will refer 1MU - is equal to 1cGy at maximum depth or under reference calibration setup of linac will have; 100 MU in 100 cm SDD for 10 x 10 cm^2 FS at d_{max} we will profit the dose of 1Gy (IAEA TECDOC 1455).

Figure 2. Gafchromic films after irradiation with diferent MU

The representation of optical density based on work, is calculated for the case when films are used for the calibration procedure. For densitometers that do not read optical densities directly, the grid of optical densities (D_j) and the standard deviation σ^i of the optical density (D_j) for a dose can be calculated as follows (Lewis Micke Yu Chan 2012):

$$netOD^i(D_j)=OD^i_{exp}(D_j)\text{-}OD^i_{unexp}(D_j) =log_{10}\frac{I^i_{unexp}(D_j)-I_{bckg}}{I^i_{exp}(D_j)-I_{bckg}}$$

when $I^i_{exp}(D_j)$ dhe $I^i_{unexp}(D_j)$ are the exposure readings and not the film exposure, while I_{bckg} is the intensity transmission value. The delivered dose (D) versus the optical density measurement is done using the analytical form

$$D_{fit} = b * netOD + c * netOD^n$$

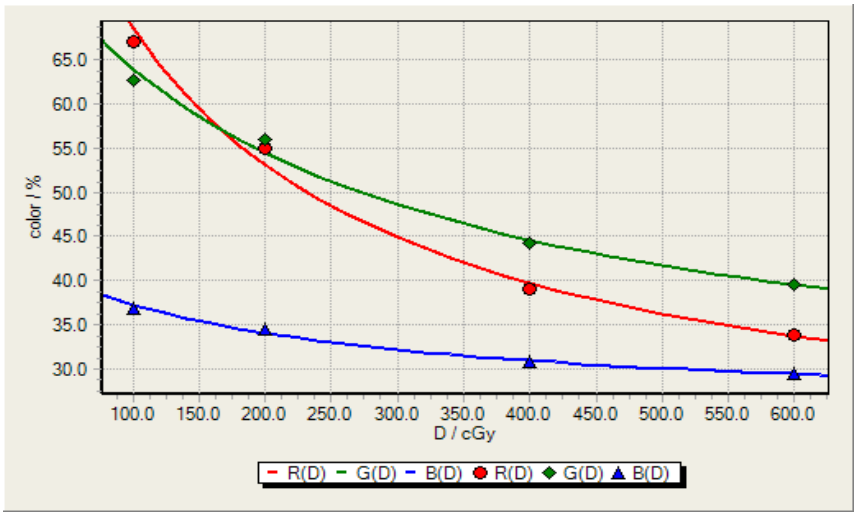

Figure 3 Calibration curve of response to radiation dose according to colors during densitometric scanning

Uncertainty analysis of dose measurements for gafchromic films presents the separation of experimental contributions from the contributions of uncertainties when obtaining the calibration curve.

The relative experimental uncertainty of the measured dose for the analytical functional form is given by the equation:

$$\sigma_{D_{exp}}(\%) = \frac{\sqrt{(b + n * c * netOD^{n-1})^2 * \sigma_{netOD}^2}}{D_{fit}} * 100$$

With σ_{netOD} calculated when we used the equation above ekuacionin and dhe relative uncertainty is given as :

$$\sigma_{D_{fit}}(\%) = \frac{\sqrt{netOD^2 * \sigma_b^2 + netOD^{2*n} * \sigma_c^2}}{D_{fit}} * 100$$

When σ_b and σ_c are uncertainty parameters.

Finally, the total relative uncertainty for the measured dose described above for the functional form is calculated

as: $\sigma_{D_{tot}}(\%) = \frac{\sqrt{netOD^2 * \sigma_b^2 + netOD^{2*n} * \sigma_c^2 + (b + n * c * netOD^{n-1})^2 * \sigma_{netOD}^2}}{D_{fit}} * 100$

These value uncertainties are expressed with the gamma index γ, during the dose evaluation process through the densitometer of the computer program. Through the electronic densitometer, after scanning the films irradiated with doses and with well-defined monitoring units, with a special EPSON V750 PRO optical scanner, we manage to obtain the values of the calibration curves for the red, green and blue colors, figure 2 (Schoenfeld A, et al 2014). The most basic dosimetry with EBT3 film uses only the film response of a single-color channel.

For doses <10 Gy the red channel is preferred. A calibration response function defines the average relationship between the measured response in the color channel and the dose applied to the film. The beauty of this method is that any signal in the measured channel converts to dose. However, any artifacts disturbing that signal that not dependent on the dose will just corrupt the dose value. For instance, if the thickness of the active layer is 2% less in one

location the signal in the response channel will be proportionally less as will the indicated dose. Single channel dosimetry is unforgiving of artifacts that are dose-independent.

Conclusions

The results of the film analysis confirm the EBT3 gafchromic film data. The data show the high sensitivity of EBT3 films to radiation. EBT3 films during image processing with the EPSON V750 PRO scanner have shown a high response when reducing the radiation on the film in portrait and landscape settings. The idea of using Gafchromic films in radiotherapy is that they do not replace absolute dosimetry with ionization chambers and high-quality phantoms but complement it as best as possible by creating digital maps of the incident radiation. Gafchromic EBT3 filaments have a good incident radiation response and the measured incident dose difference with the estimated one is 2%.

If EBT3 film is used for absolute dosimetry, it is important to recognize the effects of post-exposure changes and adopt a working procedure to measure all films, including calibration films, in the same time after exposure. Since the effects of changes after exposure are proportional to log(time), it would be preferable not to measure or scan films immediately after exposure because timing errors of measurement can have a significant effect on dose accuracy. To keep these errors small, it is suggested to wait 1-2 hours after exposure before measuring or scanning EBT3 films. If it is possible to wait and scan the films after about 24 hours, a delay of two or three hours should have negligible impact in accuracy**.**

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