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Characterization of HD-V2 Gafchromic Film for Measurement of Spatial Dose Distribution from Alpha Particle of 5.5 MeV

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***Abstract*—**The purpose of this study was to investigate the response of the newly released Gafchromic HD-V2 film for alpha particle of 5.5 MeV. Gafchromic HD-V2 was exposed to alpha particles of energy 5 MeV from ^{241}Am for different durations. Then the films were scanned with a flatbed scanner. The dose response curve up to 2200 Gy has been achieved. The film's reproducibility and sensitivity were evaluated. The results obtained show that the net optical density increases almost exponentially with the increase in the exposure time, and it becomes saturated after prolonged exposure times. The red channel shows the highest sensitivity, with a value of 4 x 10-3 Gy-1 at netOD of 0.4. The inter-film reproducibility was measured and the relative uncertainty found was 1.7 %, 2.1 % and 2.3 % for grey, red and green channels, respectively.

***Keywords*—**Alpha dosimetry, ^{241}Am, Gafchromic film.

I. Introduction

THERE has been increased interest in using short range particulate emitters, such as alpha particles, for use in therapeutic applications [1], [2], [3], [4]. The use of alpha particles are advantageous in radiological applications because of their high LET and because their effect is independent of the dose rate. The high LET of alpha particles enables them to deliver lethal doses to the target while minimizing the dose to the surrounding area. However, the dose determination of alpha radionuclides is a challenge because of the stochastic nature of the energy distribution at the target [5]. The precise calculation of alpha doses requires knowing the details of source size, density, geometry, composition and radionuclide contents. In the absence of this information, point source geometry is always assumed. This leads to overestimation of the calculated dose because of the discounting of the degree of self-absorption within the particle [6]. An alternative approach is direct measurement of the absorbed dose in contact with the target. The alpha dosimetry technique should exhibit a number of features including very thin layer, energy dependence and tissue equivalent. The newly released Gafchromic HD-V2 film is a suitable candidate for measurement of the absorbed dose from alpha emitter radionuclides because its active layer (8 µm thick, ρ=1.2 g/cm^3) has no protective or surface layer. The active layer is coated with a clear 97 µm polyester substrate. [7]. This type of Gafchromic film exhibits good dosimetric features including high spatial resolution, wide dose range (10 Gy - 1000 Gy), good reproducibility, energy-independent response and dose rate independence. Moreover, the HD-V2 can be used for dose mapping of various sources and a wide range of charged-particle energies down to 5 keV or lower [7]. An older version of Gafchromic HD (HD-810) film has been successfully used to measure skin dose distribution from the Dounreay hot particles (β/γ emitters) [8]. HD-810 has also been used to measure skin dose rates from Ra-226 samples (alpha emitter). The measured skin dose rates were underestimated by the calculated values by several times. The big difference between the actual measurements and calculated estimates was attributed to a lack of precise information about alpha source density, shape and activity [6]. Recently, measurements of the spatial resolution and sensitivity of HD-V2 to protons and alpha particles (1.4 MeV and 2.58 MeV) have been made using HD-V2 films. The measured position resolution was about 82 µm [9].

The aim of this study was to utilize the newly released Gafchromic film type HD-V2 to measure the spatial dose distribution from ^{241}Am source. The study also evaluated some dosimetric characteristics including film's reproducibility and sensitivity.

II. Materials and Methods

Two sets from one batch of Gafchromic sheet (type HD-V2) was cut in 2 cm x 2 cm. Each was checked visually for any scratches or smudges. The films were kept in an opaque, light-tight envelope. For calibration, the films were irradiated by a Varian linear accelerator using 6 MV photon beam and a 10 cm x 10 cm field and exposed perpendicularly to the radiation beam. During exposure, the film pieces were placed in a solid water phantom at a maximum dose of 1.5 cm. Both films were read after 24 hours using a flatbed scanner. This delay time was necessary to allow the irradiated films to stabilize [10]. The films were scanned on LaserJet pro M 1530 flatbed scanner in both greyscale and colorscale at a resolution of 1200 dpi and 8 bit dynamic range, and then analyzed using a commercial image processing program (ImageJ), developed by the National Institute of Health (NIH), USA.

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The alpha source used in this study was ^{241}Am plane source. The source has several alpha energies, most of which were in the range of 5.5 MeV: 5.39 (1.7%) 5.44 (13.1%) 5.486 MeV (85.2%) and 5.443 MeV (12.8%). The dose contribution from beta and gamma radiation was not considered in the current study. The dose measurements were carried out by mounting the ^{241}Am source onto the film, with its sensitive layer uppermost, and then placed in a light-impervious box to minimize errors due to the small light sensitivity of HD-V2 films. There was 0.7 cm of air between the source surface and the film surface. The total mass thickness between the source surface and the middle of the film's active layer was 1.853 mg/ cm^2.

The ImageJ provides pixel values (or intensity) for the scanned film, which can be converted into net optical density (netOD) using the following formula:

$$\text{netOD} = \log_{10}\left(\frac{I_{unexp}}{I_{exp}}\right) \quad (1)$$

whereI_{unexp} and I_{exp} are intensities measured for unexposed films and exposed films, respectively.

The sensitivity of the film, defined as the netOD per unit dose, was measured with dose ranges from 0 to 2000 Gy.

III. Results and Discussion

A number of the 12 films were irradiated for different exposure times, ranging from 0.33 hour to 20 hours. The irradiated films were scanned on both greyscale and colorscale and saved as TIF format. The analyzed area or the region of interest (ROI) was a 5 mm x 5 mm area at the center of each film. For each scanned image, the netOD and standard deviation at the ROI was calculated. Fig. 1 presents the absorbed dose as a function of netOD. The three color channels (grey, red and green) represent different dose responses to irradiation. The red dose response curve is almost linear up to ~ 330 Gy. The grey and green dose response curves can be determined using polynomial function. The standard deviation of the measured netOD (σ_{netOD}) ranges from 1.43 to about 6.0. It is noted that green and grey reaches saturation at high doses, i.e., > 1000 Gy. To extend the dynamic range, an appropriate combination between the different color channels can be made [11].

TABLE I
THE DOSE REQUIRED TO ACHIEVE A NET OPTICAL DENSITY OF 0.4 FOR DIFFERENT ALPHA PARTICLES OF ENERGY

Dose @ netOD of 0.4 (Gy)		
1.5 MeV [(1)]	2.58 MeV[(1)]	5.5 MeV
540	280	100 (red channel)

[(1)] M. J. Schepis et cl, "Measurement of the sensitivity and spatial resolution of radiochromic film using ion beams and X-rays", Abstract submitted for the DPP12 Meeting of The American Physical Society, 2013

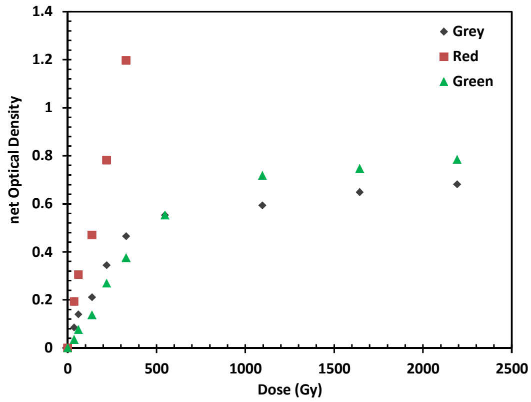

Fig. 1 HD-V2 dose-response curves for ~ 5 MeV alpha particles

Fig. 2 shows the sensitivity curves for the four color channels (red, green, blue and grey). The red channel shows the highest sensitivity in the dose range from ~ 1 Gy to ~ 330 Gy, and it is about four times higher than the green channel at 60 Gy. The blue channel shows the lowest sensitivity. Because HD-V2 is mainly designed to measure high radiation doses, it is expected to have lower sensitivity than other types of Gafchromic films such as XR-T and EBT films[12], [13]. Recently, M. J. Schepis et cl (2013) have measured the sensitivity of HD-V2 against two alpha particle energies (1.4 and 2.53) [14]. Table I presents a quantitative comparison between different alpha particles energy (1.4, 2.58 and 5.5 MeV). This is done by identifying the dose required to achieve a netOD of 0.4. The comparison shows that the sensitivity increases as alpha particle's energy increases. It is worth noting that this is an approximate comparison because the sensitivity of the film depends on several factors, including experimental design, scanning system employed and source of irradiation used [15].

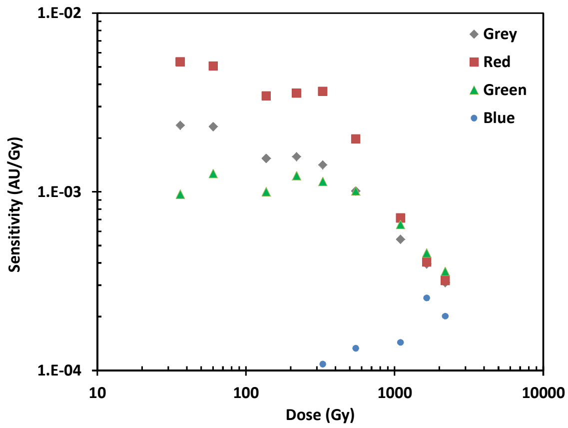

Fig. 2 Dose sensitivity curves for HD-V2 films as a function of absorbed dose delivered using alpha sources (5 MeV)

Fig. 3 displays the false color netOD map and the netOD profile across the image and the three-dimension pixel value distribution for three hours of exposure, as analyzed using the green channel. It is worth noting that the false image and profile image appear symmetric, which is an indication of the symmetry of the source. From the netOD profile, the diameter of the active source may range from 1 mm to 1.5 mm. There is no available information about the actual diameter of the source. The steep dose gradient is clearly evident as one move away from the center. The steepness of the dose variation is a strong function of the source size, source energy and depth.

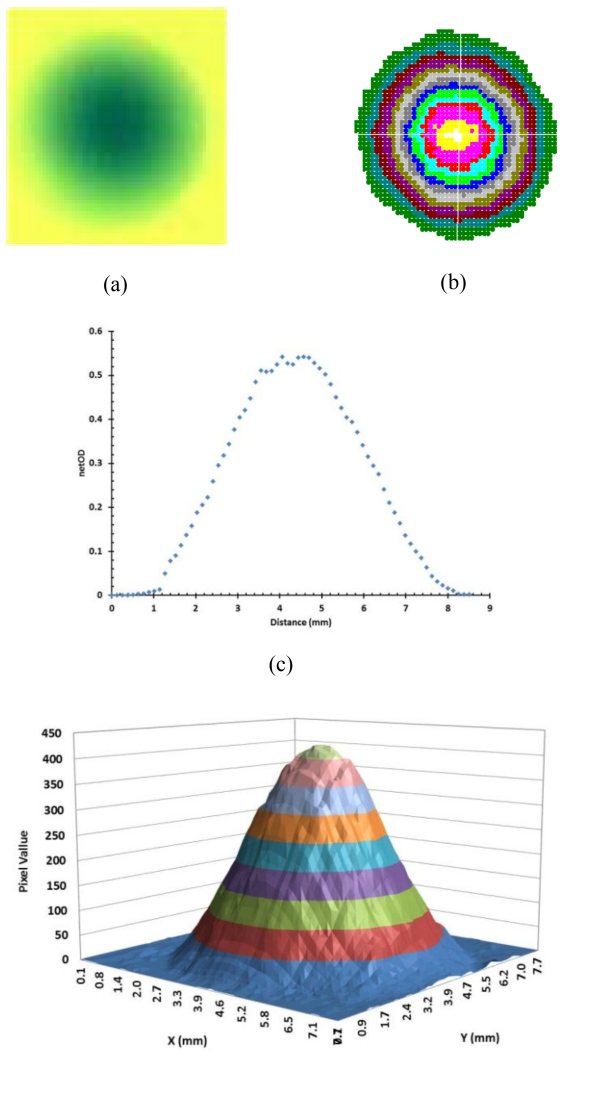

Fig. 3 (a) HD-V2 film exposed for 5 hours from ^{241}Am alpha source, (b) false color optical density map, (c) net optical density profile across the image, and (d) the surface optical density distribution. The film was scanned using a resolution of 200 dpi with a LaserJet pro M 1530 flatbed scanner and generated by a green color image

An investigation of inter-film reproducibility was conducted by exposing five films for the same exposure time (ten hours). Each film was read five times to exclude single film reproducibility. The relative uncertainty found was 1.7 %, 2.1 % and 2.3 % for grey, red and green channels, respectively. This is a reasonably good result and indicates that the stochastic nature of the energy distribution of the alpha particles has no effect on the inter-film reproducibility. It also provides information about the uniformity of the film.

IV. Conclusion

This study investigated the response of the newly released Gafchromic HD-V2 film toalpha particle of 5 MeV. The HD-V2 film provided high spatial resolution 2D dose map for alpha particles of 5 MeV (^{241}Am). The results obtained show that the net optical density increases almost exponentially with the increase in the exposure time and as it becomes saturated over prolonged exposure times. The red channel shows the highest sensitivity for the dose up to 330 Gy, whereas the green and grey channels are suitable for higher doses. The film's inter-reproducibility is less than 3%. This reproducibility contributes to uncertainties in the overall experiment.

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