Gafchromic XRQA-2 film for Strontium-90/Yttrium-90 (Sr-90/Y-90) Detection

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Abstract. Gafchromic XRQA-2 radiochromic film is an effective tool for quality assurance and dose assessment in kilovoltage radiotherapy and diagnostic applications. This work is done to study the response of Gafchromic XRQA-2 film for beta particle detection. Materials investigated are the beta particle source, Sr-90/Y-90 and Gafchromic XRQA-2 film. The film is exposed to Sr-90/Y-90 for different duration of time and scanned with flatbed scanner. The film is analyzed by using a ImageJ software in the red mode. The result shows that the net reflected optical density (Net ROD) increased linearly with increase in time. The Net ROD and time integrated specific surface activity increased linearly with time. The Net ROD for Sr-90/Y-90 is from 0.00 to 0.13. Thus, the Net ROD is highly related to the duration of time exposed to the beta source.

1. Introduction

Gafchromic XRQA film is a radiochromic film designed specifically to be used in radiology and dosimetry applications. It is a reflective type of films which change in color upon irradiation and does not require any chemical process for its development. The change in the optical density (OD) of the film is directly proportional to the absorbed dose of ionizing radiation. XR-QA2 Gafchromic film model is a new successor to the previous XR-QA film model. This film consists a radiation sensitive layer 25 μm thick and attached to the 97 μm thick white reflective polyester surface layer. On top of the sensitive layer, a 20 μm thick pressure sensitive adhesive which a 97 μm protective yellow polyester is over-coated [1]. The atomic composition of the active layer of the film is made up of H, N, O, C, Li, Br, Bi and Cs [2]. The XR-QA2 film contains Bi2O3 in its sensitive layer which aids to boost the photoelectric effect at low energies. The addition of bismuth lowered the otherwise noteworthy energy dependent response of XR film models [3]. The dose range for this XR-QA2 film is 0.1-20 cGy [5]. Figure 1 shows the layers of the Gafchromic XRQA-2 film. The numerous advantages of the radiochromic film, which have high spatial resolution, relatively small energy dependent response [4,5] near to tissue-equivalence and high dose distribution measurement have make it a powerful dosimetry tool for radiotherapy treatment verificiation and quality assurance [1].

Beta particle is emitted during a radioactive process called beta decay. Beta ray is a high speed of electron or positron emitted in the radioactive decay of an atomic nucleus. When a radioactive nucleus undergoes beta decay, the daughter nucleus contains the same number of nucleons, A as the parent nucleus, but changed by 1 in atomic number, Z which means the number of protons has changed [6]. Beta source, Strontium 90 (Sr-90) disintegrates to the ground state of Yttrium 90 (Y-90) by emitting...
beta minus (β-1) radiation. Y-90 is then decay to Zr-90 by β-1 with energy of 2.28 MeV. Thus, the maximum beta energy of this radioactive substances is 2.28 MeV. 100% of beta is emitted from this source. There is no gamma and alpha rays emitted from this source. The physical half-life is 28.2 years. Strontium 90 should be shielded with Plexiglas with a thickness of 9.2 mm. Figure 2 shows the decay scheme of the Strontium 90. Special precautions need to be taken during handling this source. The use of tools such as tongs, forceps and plastic books is crucial for indirectly handling unshielded sources [7]. The Strontium-90 source that is available in the Universiti Sains Malaysia (USM) laboratory have an initial activity of 5μCi. The source was bought in 1971.

A lot of studies have been conducted to measure the beta particles detection. However, the problem arises where a specific beta detector is not available to detect the beta particles. Therefore, this study is done to measure the beta particles from beta emitting nuclides using Gafchromic XRQA-2.

![Transparent Yellow Polyester- 97 μm](image)

![Adhesive layer- 20 μm](image)

![Active layer- 25 μm](image)

![Opaque White Polyester- 97 μm](image)

**Figure 1.** Gafchromic XRQA-2 film composition.

**Figure 2.** Decay scheme of Sr-90.

2. Materials and Methods

2.1. Film irradiation

Beta source Sr-90/Y-90 is placed on the cardboard washer of 2 mm thick to prevent direct contact of the source with the film as shown in Figure 3. The film size is 2 cm × 3 cm dimension. The purpose of the cardboard washer is to prevent the crosswire formation on the film when the Sr-90 is placed on the film. The formation of the crosswire on the film affect the mean pixel value reading. The film is exposed for 16 hours. After 16 hours, the film is observed to see whether there are any color changes on the film. The procedures are repeated by changing the time of the exposure to 24 hours, 36 hours, 48 hours, 72 hours and 96 hours using different films.

![Beta source (Sr-90) Cardboard washer XRQA-2 Film](image)

**Figure 3.** Schematic diagram of Sr-90/Y-90 irradiation on XRQA-2 film.
2.2. Film scanning and analysis
After the irradiation of beta source to the film, the film is left for 24 hours before scanning procedure can be done. The polymerization process in radiochromic film lasts for extensive time after irradiation [8,9,10]. The significance of the continued polymerization is that the optical density (OD) grows over time. Therefore, films should be left for at least 6 hours and preferably 24 hours before scanning. This is to minimize uncertainties related with post-irradiation coloration in both the calibration films and experimental films. The film should be scanned after approximately the same time interval following irradiation [11]. In this study, the film is scanned using Epson Perfection V700 professional flatbed scanner. The scanner is set with resolution of 72 dpi, image pixel of 48-bits, reflective mode is chosen since it contains 16 bits per colour mode in red, green and blue (RGB) mode which sufficient for the analysis [2]. The scanner is warmed up several times without any object placed in the scanner bed before the actual scanning of the film [12]. The film images analyzed with Image-J using 16-bit images in TIFF format [2]. These images were analysed using the red mode in the ImageJ software as it gives a higher mean pixel value compared to the green and blue mode [13].

The main quantities that can describe the response of XRQA-2 Gafchromic film to radiation are the mean pixel value (MPV), net reflectance optical density in equation 1 and reflectance in equation 2. The base of XRQA-2 film is opaque white polyester. For opaque films, the quantity of choice would be reflectance [1]. The mean pixel value is a quantity which the value is obtained directly from the ImageJ software.

\[
\text{Net ROD} = \log\left(\frac{\text{MPV}_u}{\text{MPV}_t}\right)
\]  

(1)

Where MPV_u is the mean pixel value of the reflected intensity of unexposed film where the maximum pixel value is found and MPV_t is the mean pixel value of the reflected intensity of irradiation [13].

\[
\text{Reflectance} = \frac{\text{MPV}_t}{2^{16}}
\]

(2)

Orientation and positioning for film scanning process is crucial. The artifacts associated with the radiochromic films with flatbed scanner are known as the orientation effect. The film is scanned in landscape mode because of the lateral response artifacts on Charge-Coupled Device (CCD) scanner is smaller compared to portrait orientation. It is recommended that the same orientation be used for Gafchromic EBT film analysis for accurate film dosimetry apply to Gafchromic XRQA film [13].

3. Results and discussion
3.1. 5µCi Strontium 90/Yttrium 90
Table 1 shows the main quantitate response of beta particle from Strontium 90/Yttrium 90 on Gafchromic XRQA-2 film in terms of mean pixel value, reflectance and net reflectance optical density. According to Figure 4, the MPV_t is exponentially decreased as the time of irradiation increased. On contrary, Figure 5 shows that Net ROD is linearly increased with the irradiation time. The Net ROD is a quantity that shows the difference in pixel value before irradiation and after irradiation where the film changes its colour upon irradiation. The higher values of Net ROD show higher degree of film blackening due to the absorption of beta particle.
\[ y = 64549e^{-0.003x} \]
\[ R^2 = 0.9893 \]

\[ y = 0.0014x + 0.0058 \]
\[ R^2 = 0.9808 \]

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Table 1. Variation of Reflectance, Net ROD and MPV with irradiation time.

| Time (hours) | Average MPV_t | Average MPV_t | Reflectance | Net ROD |
|--------------|---------------|---------------|-------------|---------|
| 0.00         | 0.00          | 65073         | 1.00        | 0.00    |
| 16.00        | 61879         | 65535         | 0.94        | 0.02    |
| 24.00        | 59626         | 65073         | 0.91        | 0.04    |
| 36.00        | 56701         | 65535         | 0.87        | 0.06    |
| 48.00        | 52361         | 65076         | 0.80        | 0.10    |
| 72.00        | 50703         | 64947         | 0.77        | 0.11    |
| 96.00        | 48240         | 65507         | 0.74        | 0.13    |

Figure 4. The MPV value with respect to irradiation time.

Figure 5. Response of MPV_t and Net ROD against irradiation time.

Another quantity that can be analysed from the film which is the time-integrated specific surface activity (A) which is given by equation 3 [14]. This quantity describes the distribution of the source in isotropically dimension at a fixed area.

\[
A = \frac{Q t}{\pi r^2}
\]

Where Q is the source activity, \( r \) is the source radius, \( t \) (hour) is the exposure time and \( \pi r^2 \) is the area of the circle.

The current activity of Sr90 is 1.65 µCi or 61.05 kBq. The area of the exposed film is 0.19 cm² with a radius of 0.25 cm. Table 2 shows the variation of A with irradiation time and Net ROD. From the Figure 6, it can be concluded that the Net ROD is linearly increased to A with a regression coefficient of 0.9808.
Table 2. Variation of A and Net ROD with irradiation time.

| Time (hours) | A (kBq cm⁻² h) | Net ROD |
|--------------|----------------|---------|
| 0.00         | 0.00           | 0.00    |
| 16.00        | 5141.05        | 0.02    |
| 24.00        | 7711.58        | 0.04    |
| 36.00        | 11567.37       | 0.06    |
| 48.00        | 15423.16       | 0.10    |
| 72.00        | 23134.74       | 0.11    |
| 96.00        | 30846.32       | 0.13    |

Figure 6. Net ROD against A.

4. Conclusion
This project shows that Gafchromic XRQA-2 radiochromic film is sensitive to beta particles. The MPVt and Net ROD shows the exponential relationship against time, whereas the relationship between Net ROD and time-integrates specific surface activity shows a linear relationship with respect to irradiation time.

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