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To cite this article: E E Carpentier *et al* 2017 *J. Phys.: Conf. Ser.* **847** 012052

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Characterization of a radiochromic silicone dosimeter

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Abstract. A radiochromic silicone based dosimeter has been fabricated that allows for three-dimensional (3D) dose verification. This paper characterizes the silicone dosimeter and verifies previous results found by other research groups. Using a recipe found to be dose rate independent, we identify the spectra of the dosimeter irradiated to different doses and verify that the response from different dose rate deliveries is constant within uncertainty. The reproducibility of a response from identically irradiated and stored cuvettes is also investigated. A noticeable difference in response indicates that there is an inhomogeneous distribution of active ingredients due to the viscous nature of the dosimeter during fabrication. Irradiating multiple cuvettes to the same dose in different fractions shows that the response decreases as the number of fractions increases.

1. Introduction

3D dosimetry has been of much interest to the radiation oncology community [1]. Deformable 3D radiochromic dosimeters have recently been developed that use silicone to spatially fixate dose information [2-5]. Silicone dosimeters are deformable and may be formed to any clinically relevant shape, allowing for assessment of new features, such as deformable image registration algorithms in radiation delivery planning [6]. DeDeene *et al* [2, 3] and Høye *et al* [4] have collectively identified many properties of silicone dosimeters containing leucomalachite green (LMG) as a dose indicator and chloroform as a sensitizer, such as the absorption spectra when exposed to UV light [3], dose rate dependence [2-4], effects due to fractionation of dose delivery [4], short term and long term sensitivity stability [3, 4], independence of response from photon energy [2], and the effect cuvette temperature during irradiation has on the final sensitivity [3].

Recently, Høye *et al.* identified an optimal concentration of ingredients that eliminates dose rate dependence using 0.26% w/w LMG and 1% w/w chloroform, creating a dose rate independent dosimeter [5]. In this paper, the results of further investigations into these silicone radiochromic systems are reported to reproduce and confirm the results found in these previous studies, as well as further characterize the dosimetric properties of silicone dosimeters.

2. Materials and Methods

2.1. Experimental setup

The dosimeters were fabricated by dissolving 0.26% w/w LMG in 1% w/w chloroform. After the LMG was dissolved, this solution was added to the Sylgard 184 elastomer and was thoroughly mixed. The Sylgard 184 curing agent was added in a 1:10 ratio w/w with the elastomer. This mixture was then



vigorously stirred for several minutes. After thoroughly combining the ingredients, the solution was desiccated until all bubbles disappeared. The dosimeter solution was separated into disposable 4.5 mL cuvettes and left to solidify for at least 72 hours in the dark at room temperature.

Irradiations were performed using 6 MV photons and delivered using various Varian linacs in our centre. Cuvettes were irradiated at a SAD = 100 cm, using 10 x 10 cm² fields at 1.5 cm depth in plastic water with 10 cm backscatter. Cuvettes were optically imaged using the SpectroVis Spectrophotometer (Vernier, Beaverton, OR, USA) with white diffuse light, contributing an uncertainty of ± 0.002 to optical attenuation data. All attenuation information was taken at the peak wavelength of 626.6 nm.

2.2. Irradiation

Seven cuvettes were irradiated to 0, 5, 10, 15, 20, 25, and 30 Gy at 2 Gy/min to examine the dose dependence of the absorption spectra over wavelengths ranging from 380-700 nm. The dose rate dependence of this recipe was verified by irradiating three sets of six cuvettes to various doses at different dose rates: 2, 4, and 6 Gy/min. Each cuvette was scanned thirty minutes after irradiation in the spectrophotometer to determine the change in optical attenuation. This experiment also monitored six cuvettes, three irradiated to 10 Gy and three irradiated to 20 Gy to determine whether identical cuvettes behaved consistently after irradiation. The cuvettes were scanned every 5 minutes after irradiation for the first hour and then every few days to determine the reproducibility of the temporal changes. These cuvettes were stored in the dark at room temperature between scans. Finally, the effects of dose fractionation were investigated by irradiating four cuvettes to 20 Gy in 1, 2, 5, and 10 fractions at 6 Gy/min. After delivering each fraction, we allowed a 30 second pause before delivering the next fraction.

3. Results

The spectra of silicone cuvettes irradiated to various doses are shown in figure 1. Figure 2 shows the change in optical attenuation for cuvettes irradiated with different dose rates. The sensitivity of the silicone dosimeter is $0.0232 \pm 0.0005 \text{ cm}^{-1}\text{Gy}^{-1}$ at 2 Gy/min, $0.0229 \pm 0.0004 \text{ cm}^{-1}\text{Gy}^{-1}$ at 4 Gy/min, and $0.0220 \pm 0.0009 \text{ cm}^{-1}\text{Gy}^{-1}$ at 6 Gy/min. The sensitivities at different dose rates vary only within measurement error thus no significant dose rate dependence could be demonstrated.

Reproducibility of the response among identical cuvettes shows that the identical silicone dosimeters can vary significantly. Figures 3 and 4 shows cuvettes irradiated to 10 Gy and 20 Gy are distinguishable despite being irradiated and stored identically. Multiple batches of silicone produced similar results (not shown). The silicone elastomer's viscosity requires vigorous stirring for several minutes during fabrication to evenly distribute active ingredients. These differing results may result from manual stirring being insufficient to create a homogeneous distribution of active ingredients, creating different concentrations of LMG in each cuvette and producing different responses upon irradiation.

Figure 5 shows the response when cuvettes are irradiated to 20 Gy with a different number of fractions. From this plot it appears that increasing the number of fractions will decrease the response. This is in agreement with results found by Høye *et al.* However, the large variability in response for cuvettes irradiated to the same dose requires allocating inherent uncertainty to individual measurements and drawing conclusions based on that level of confidence.

4. Conclusions

The measurements summarized in this work support previous reports of dose dependence [3], dose rate dependence [5], and fractionated dose delivery [5], demonstrating the consistency of radiation dosimetric properties in individual samples of dosimeters. However the observed problem of reproducibility in the temporal measurements, not reported previously, indicates that cross calibration between and within batches will need careful attention, and readout will need to be performed soon after irradiation. Further work is underway to establish how the silicone dosimeter fabrication process affects performance, in particular a new method for mixing the silicone dosimeter's ingredients is being considered to reduce response variations.

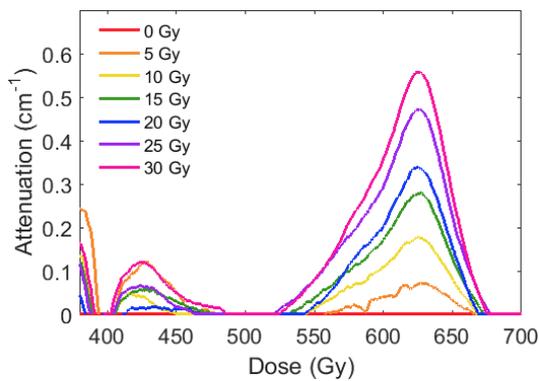


Figure 1. Plot of silicone dosimeter spectra irradiated to different doses.

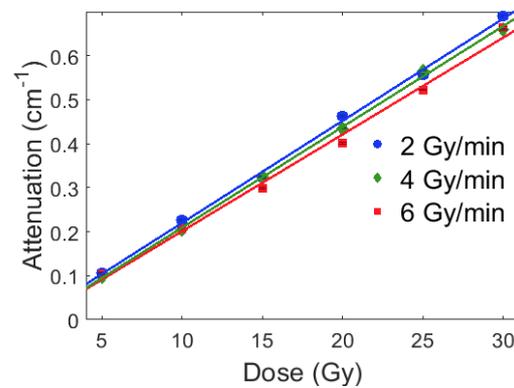


Figure 2. Cuvettes irradiated to various doses at different dose rates. Error bars are smaller than the symbol size.

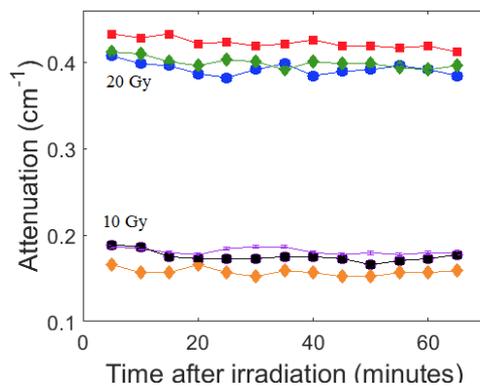


Figure 3. Reproducibility of identical cuvettes in the first hour after irradiation.

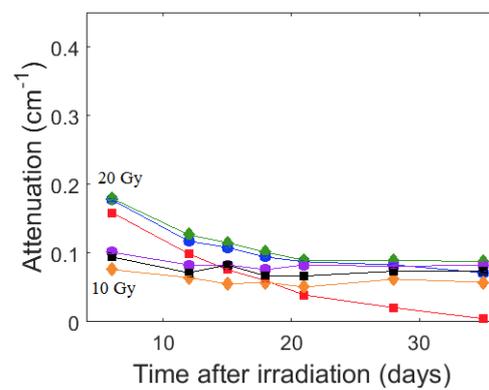


Figure 4. Reproducibility of identical cuvettes over several days after irradiation.

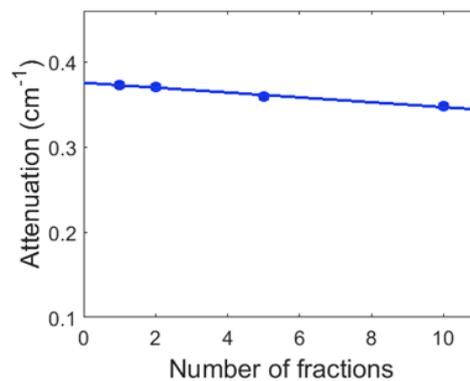


Figure 5. Results from irradiating cuvettes to 20 Gy with a different number of fractions.

5. References

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