

Turnbull Blue Gel (TBG) evaluation as optical dosimeter

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Abstract. The radiochromic Turnbull Blue Gel (TBG) is sensitive to X- and γ -rays. When exposed to high-energy radiation, TBG can simulate biological tissues, so this gel has potential use in ionizing radiation dosimetry. After irradiation, the yellow TBG changes to the blue Turnbull Blue dye. This work aims to evaluate how TBG responds to exposure to ultraviolet, visible, and infrared radiation from the sun. The gel was irradiated with a solar simulator, which sensitized TBG and transformed it into the Turnbull Blue dye; a change in the optical absorption ensued. The fluence values delivered by the source did not provide a linear response, but it was still possible to use TBG as an optical dosimeter. In conclusion, TBG can be applied to detect solar radiation because it is sensitive enough to measure sun exposure values at time intervals of few minutes.

1. Introduction

The main natural source of optical radiation is the sun. Exposure to the sun is necessary for the human body to produce the vitamins required for the organism to function properly [1,2]. However, overexposure to sun radiation can produce skin burns that may ultimately lead to skin cancer. Studying exposure to solar radiation is essential to understand biological responses. These studies are also important to agriculture because they cast light on photosynthetic processes and help to control the growth of fungi and other microorganisms [3, 4]. The World Health Organization recommends that personal exposure to solar radiation be monitored, so that the percentage of sun radiation received by the population can be established. In this context, optical dosimeters constitute an important tool to measure exposure to sunlight [5]. The dosimetric gel used in this work falls into the category of radiochromic gels because it is based on the radio-induced generation of the insoluble Turnbull Blue (TB) dye. During exposure of the gel to the sun, ferric ions (Fe^{III}) originating from the salt interact with the electrons from the ionized medium. The Fe^{III} ions are then reduced to ferrous ions (Fe^{II}), which subsequently interact with potassium ferricyanide, to form the Turnbull blue dye, $\text{K}[\text{Fe}^{\text{II}}\text{Fe}^{\text{III}}(\text{CN})_6]$ [6].

In radiobiology, the term "absorbed dose" refers to the energy deposited by charged particles in a mass of tissue volume $[\text{J/kg}]$ [7]. This term has been applied in different ways in photomedicine and photobiology. However, this term should not be used in the way it has been employed because it is not possible to measure the amount of energy deposited per kilogram. As the optical tissue penetration is shallow, the term ends up being understood as the energy given as fluence or energy density in an area element $[\text{J/m}^2]$ [8].

This study aimed to measure the response of the Turnbull Blue Gel after exposure to sunlight and to evaluate its ability to function as an ultraviolet dosimeter.



2. Methodology

2.1. TBG Preparation

The dosimeter composition is Agarose (4% w/w), Potassium Ferricyanide (1.5 mM), $K_3Fe(CN)_6$ and Iron(III) Chloride (0.5mM), $FeCl_3 \cdot 6H_2O$. The detail to manufacturing the TBG is better described in the reference [6]. After manufacture, the gel (liquid) was placed in quartz cuvettes with optical path of 1cm and kept in the dark at 7° C until use.

2.2. Irradiation

A solar simulator (Xe-3, Q-Lab Corporation, USA) was used to reproduce the solar irradiance in the ultraviolet, visible, and part of the infrared spectral regions. Before exposure, the spectral irradiance was measured with a calibrated spectroradiometer (USB2000, Ocean Optics, USA). The detector and the TBG samples were placed 10 cm below the source. The samples were irradiated at 25°C. Eleven samples were employed in this experiment. One sample was not irradiated and served as control of the natural formation of TB dye in the gel. The other ten samples were irradiated for different times, from 1 to 10 minutes. After irradiation, the samples were kept in the dark at 25°C until the absorbance was measured.

2.3. Absorbance measurement

To assess how the color of TBG changed inside the cuvettes, the absorbance of the samples was recorded between 350 and 900 nm. The spectral resolution was 1 nm. The spectra were collected on an Ultrospec 2100 Pro, UV-Vis Spectrophotometer. The blank consisted of a quartz cuvette containing Milli-Q water.

3. Results

Figure 1 shows the spectral irradiance of the solar simulator. The total irradiance was 443.8 W/m². The UV, visible, and infrared radiation corresponded to 11, 71, and 18% of the total irradiance, respectively.

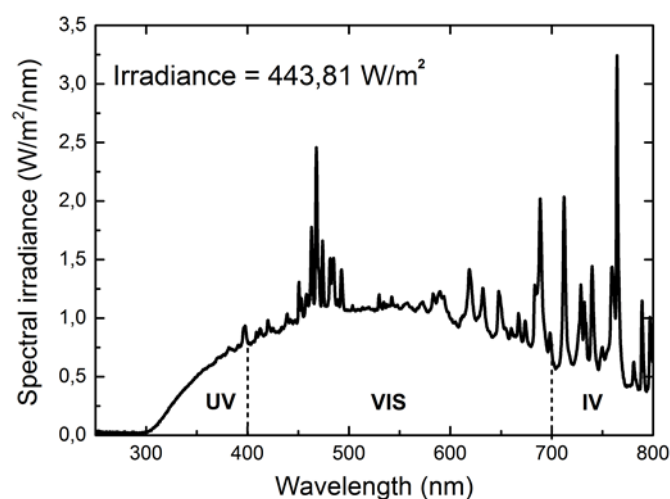


Figure 1. Spectral irradiance of the solar simulator used in this work. The data was obtained by placing the detector at the same place of the gel samples.

When the gel was exposed to high-energy radiation, the radiolysis of water took place. Consequently, free radicals emerged and reduced Fe^{III} ions to Fe^{II} , to give the TB dye. There has been much discussion about the categorization of UV radiation from the sunlight spectrum as ionizing or non-ionizing radiation with respect to water. The radiation used in this study, albeit non-ionizing, can place highly reactive ions of the solution in excited states, which can also reduce ferric ions and produce the

TB dye. This can be seen below in the comparison of the absorption spectra of the samples recorded before (Figure 2) and after (Figure 3) irradiation; Figure 4 shows the difference between them.

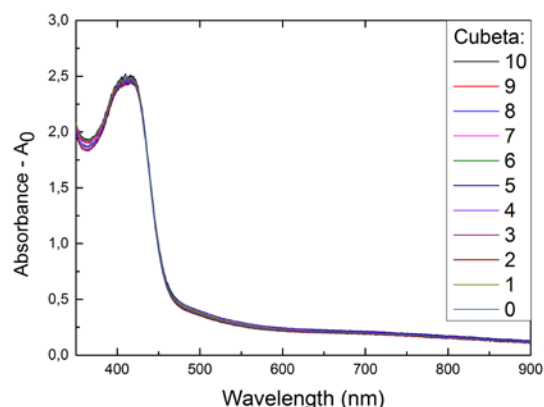


Figure 2. Absorption spectra of eleven samples before irradiation.

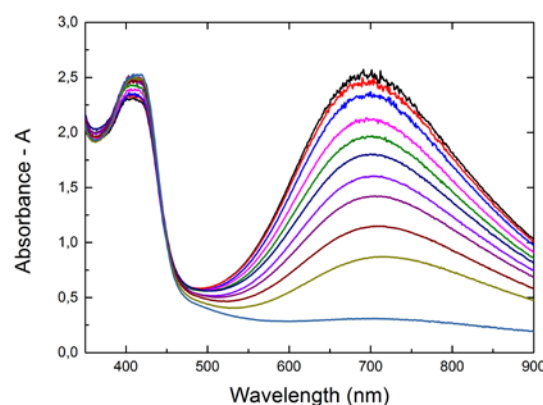


Figure 3. Absorption spectra of eleven samples after irradiation.

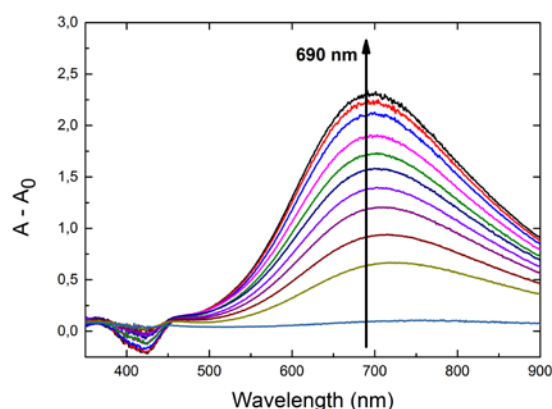


Figure 4. Absorbance difference at 690nm. The absorption peak reveals the Turnbull Blue dye formation.

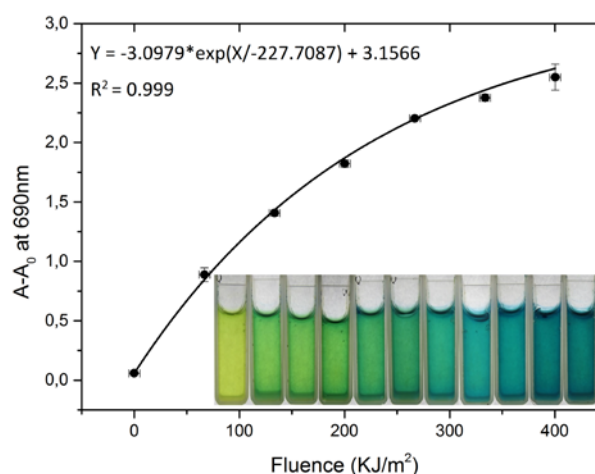


Figure 5. The gel response as a function of fluence delivered by the source. Detail: 11 samples after irradiation from non-irradiated gel to 10min.

On-going from the non-irradiated sample to the sample irradiated for one minute, the absorption changed the most significantly. Therefore, the fluence received for only one minute was enough to obtain a measurable response from the gel. If we consider 10 minutes of exposure as the maximum change in the response of the gel, the irradiation received by the sample during the first minute corresponded to 20% of the maximum response, whereas the smallest change occurred between 9 and 10 minutes (less than 5%), the period during which the curve approached saturation. Figure 5 illustrates the nonlinear relationship between the change in the absorption of the gel at 690 nm and the fluence delivered by the solar simulator. The detail in this figure shows the eleven samples used in the experiment. Considering the uncertainty of triplicate samples, it was possible to obtain a relationship expressed by the equation $Y = -3.0979 * \exp(X / -227.7087) + 3.1566$.

4. Conclusions

The dosimetric Turnbull Blue gel showed measurable and reproducible response after irradiation with a solar simulator. The spectrum issued by the solar simulator (300-800nm) consisted of UV light, the whole visible spectrum, and part of the infrared spectrum. Although it was not possible to pinpoint which

wavelength the gel was sensitive to, TBG responded to all the spectral range emitted by the solar simulator, which attested to its ability to detect and dose solar radiation.

5. References

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