Radiation Physics and Chemistry 79 (2010) 1209–1214

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

# Application of radiochromic gel detector (FXG) for UVA dose measurements

Issam Abukassem*, Mamdouh A. Bero

*Department of Protection and Safety, Atomic Energy Commission, Damascus, P.O. Box 6091, Damascus, Syria*

ARTICLE INFO

*Article history:*
Received 22 February 2010
Accepted 20 June 2010

*Keywords:*
Ultraviolet radiation
FXG gel
Optical absorbance
UVA dosimeter

ABSTRACT

Tissue equivalent radiochromic gel material containing ferrous ions, xylenol-orange ion indicator and gelatin as gelling agent (FXG) is known to be sensitive to $\gamma$- and X-rays; hence it has been used for ionizing radiation dosimetry. Changes in optical absorbance properties of FXG material over a wide region in the visible spectrum were found to be proportional to the radiation absorbed dose. An earlier study demonstrated the sensitivity of FXG gel detector to ultraviolet radiation and therefore that could give quantitative measure for UV exposure. This study focuses on the detection of UVA radiation (315–400 nm), which forms an important part (~97%) of the natural solar UV radiation reaching the earth surface. A solar UV simulator device was used to deliver UVA radiation to FXG samples. The beam was optically modified to irradiate gel samples at an exposure level about 58 W/m$^2$, which is comparable to the summer natural UVA radiation measured outside the laboratory building at midday (~60 W/m$^2$). Experimental results were used to generate mathematical second order formulas that give the relationship between UVA dose and optical absorbance changes observed at two wavelengths in the visible region of the spectrum—430 and 560 nm.

## 1. Introduction

Human exposure to ultraviolet radiation is mainly due to the sun, which is the most important source of light on earth. Solar ultraviolet radiation is composed mainly of UVC (100–280 nm), UVB (280–315 nm) and UVA (315–400 nm). However, almost all UVC and a large part of the UVB spectrum get absorbed by ozone and other gases in the atmosphere. On the other hand, almost all solar UVA passes through the atmosphere and reaches the earth surface. For example, it was reported that on a clear summer day at sea level and latitude 52° north UVB radiation comprises approximately 3.5% of terrestrial UV radiation, and UVA the remaining 96.5% (Diffey, 2004).

Generally, UV radiations have an important biological effect on living beings but excessive exposure can cause damage to human skin and eyes. The only thoroughly established beneficial effect of solar UV radiation is the production of vitamin D (Webb and Holick, 1988; Webb et al., 1989). Effects of solar UVA radiation are particularly important because UVA fraction in the solar spectrum reaching the earth surface is much higher than those of other types of UV radiations, i.e. UVB and UVC. UVA also penetrates deeper into human skin tissue when compared with UVB (NRPB, 1995). Therefore, it was reported by many studies that UVA plays a significant role in human skin carcinogenesis, immune suppression, DNA damage, wrinkling and ageing. Skin cancer is considered as one of the most common malignant neoplasms (Garland et al., 2003; Agar et al., 2004; Glanz and Mayer, 2005).

Polysulphone films and phenothiazine are frequently used as commercial ultraviolet chemical dosimeters. These detectors were found useful in measuring and recording cumulative UV radiation exposure in different environments (Othman and Baydoun, 1997; Parisi et al., 2005). Polysulphone films were also found useful for measuring high exposure of UVA radiation. Ultraviolet radiant exposure, which is given in joule per square meter (J/m$^2$), is equivalent in term to UV dose in photobiology (Paolo et al., 2007). It is worth mentioning that optical changes in absorbance properties of these films are invisible to human eye. Since effects occur in the ultraviolet region they require specific optical measuring equipment and laboratory work for evaluation (Turnbull and Schouten, 2008).

The radiochromic FXG gel was developed and used for measuring three-dimensional dose distributions for high energy radiations (Bero et al., 2000). The gel itself absorbs UV radiation to a much greater extent when compared with water (Ching-Shen et al., 1996; Diffey, 1999). Our earlier study showed that the FXG gel also has good sensitivity to UV radiations and that effects of UVA radiation exposure can be measured quantitatively using a standard spectrophotometer. It is also possible to visualise the variation in FXG optical properties that occurs in the visible region of spectrum (Bero and Abukassem, 2009). Therefore, users can estimate their UV dose level without special laboratory techniques. Furthermore, penetration depth of UVA in the gel material is comparable with that observed on human skin and eyes, where the major part of UVA beam (irradiance: $E \cong 60$ W/m$^2$) is

---

* Corresponding author.
*E-mail address:* prscientific@aec.org.sy (I. Abukassem).

0969-806X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.radphyschem.2010.06.010

absorbed within a few millimetres of the gel thickness (NRPB, 1995; Bero and Abukassem, 2009). A novel application of FXG gel for UVA detection and exposure estimation was proposed; however, the use of this gel type to simulate UVA interactions with human skin or eye still requires further investigations and more detailed studies.

It is very important to quantify the effects of UVA radiation on the FXG gel and establish a relationship between the changes observed in optical absorbance, i.e. colour change and UVA radiation dose. The essential objective of this study was to generate a mathematical relationship between UVA dose and changes in FXG absorbance, which is similar to the one applied for the well-known commercial polysulphone films (Othman and Baydoun, 1997; Parisi et al., 2005). On the other hand, this study confirms the possibility of using FXG gel for a wide range UVA cumulative dose measurements. The established experimental relationship can be used to provide important parameters needed during the application of the FXG gel detector as a UVA dosimeter. For example, this application could be useful to calculate ultraviolet phototherapy dose given for medical purpose accurately (Diffey and Hart, 1997). However, FXG can still be used directly as an exposure indicator for skin and eye protection from the harmful effects of UV radiations.

## 2. Experimental setup and materials

### 2.1. Irradiation setup

The irradiation of FXG gel samples was performed using a solar UV light simulator device that delivers UVA with exposure level equivalent to that of the natural solar UVA spectrum. The irradiation setup is composed essentially of a xenon arc lamp as the UV source (Paolo et al., 2007), with power supply model XPS-200 (Solar Light Company, Philadelphia, USA). The beam is collimated by an adapted optical system of lenses and reflecting mirror. The visible part of spectrum is then eliminated by a dichroic film and the UV portion is focused on the studied sample. Fig. 1 gives a schematic diagram of the irradiation experimental setup.

The dichroic film and other selective optical filters (WG320, WG345 and UG11) allow us to obtain the required UVA radiation spectrum and doses; Fig. 2 presents the transmission curves for these optical elements as they were given by the instrument manufacturer (Solar light Company). The dichroic film reflects UV radiation efficiently while the purple filter UG11 strengthens the dichroic film functions because it transmits UV and absorbs visible and infrared radiation. The optical filters WG320 and WG345 function is to cut off the undesirable part of UV radiation; WG320 eliminates UVC as well as short wavelengths below 295 nm and WG345 eliminates all intermediate UVB radiation.

Protection of humans from the damaging effects of solar UV radiation is an important application for UV dosimetry. Therefore, the UVA irradiation level was manipulated to be as close as possible to the average value of natural solar UVA radiation level measured at mid-day during summer (21 June–21 September 2008) in the Damascus region—Syria (N:33.30′/E:36.17′, ~1000 m of altitude). The average value for solar UVA was about $60 \pm 5\ \mathrm{W/m^2}$, measured with Optometer P9710 (Gigahertz-Optik GmbH, Puchheim, Germany). The intensity of UVA radiation beam generated at the laboratory was reduced to $58 \pm 3\ \mathrm{W/m^2}$ by applying UV neutral filters (FRQ-ND03/0.3OD and FRQ-ND05/0.5 OD, UVFS, Newport Corporation, USA). UVA beam forms a homogenous light spot of 1 cm diameter at the irradiated FXG sample position. Tests on the beam stability with time show that the source has very good output constancy with an irradiance fluctuation less than 1%.

### 2.2. FXG gel materials

The radiochromic FXG gel detector is composed mainly of pure triply distilled and deionised water. More than 95% of the final volume is water, which is obtained from Sartoriuys laboratory water purification system (Sartorius, Model Arium-611, Goettingen, Germany). The other main ingredient was the gelatin powder $(C_{17}H_{32}N_5O_6)_x$ ~300 bloom gelling strength indicator (5% by weight, Scharlau Chemie, Gato Perez, Spain). Gelatin was used to make a firm gel material detector, which is optically transparent and spatially stable. Other chemical components of the FXG materials are analytical grade ferrous ammonium sulphate hexahydrate $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ at 0.5 mM concentration (F.E.R.O.S.A. Scharlau, Barcelona, Spain), 0.1 mM of the xylenol orange-sodium salt ion indicator $C_{31}H_{28}N_2O_{13}SNa_4$ (Sigma-Aldrich Chemie, Stein Heim, Germany) and finally a small amount of concentrated sulphuric acid $H_2SO_4$ at $25 \times 10^{-3}$ M, (Surechem Products LTD, Suffolk, England). The FXG radiochromic gel was fabricated following an optimised simple procedure described elsewhere (Bero et al., 2000). Gel samples were placed in standard size UV grade quartz cuvettes (Hellma GmbH Co., Mülheim, Germany), with an optical pass length of 1 cm (Fig. 3).

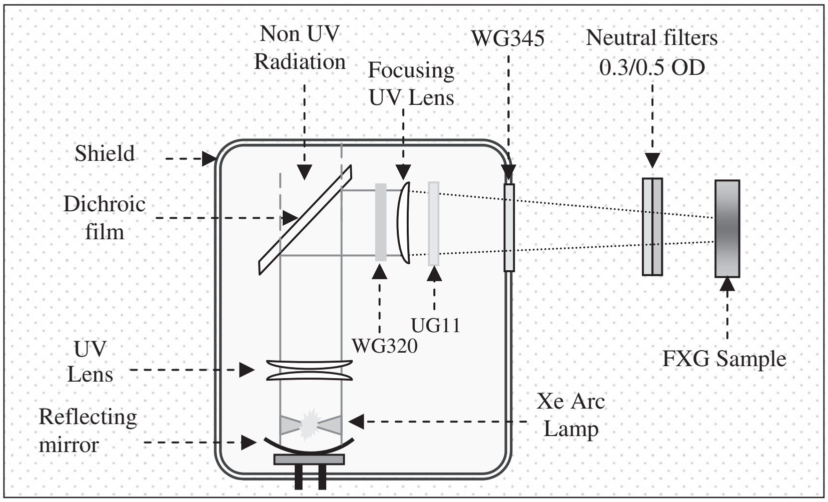

**Fig. 1.** Schematic representation of the UVA irradiation experimental setup.