

Solar UV radiation measurements with polysulphone

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Abstract: In order to optimize the UV exposure of humans, an understanding of the complex solar UV environment is necessary. Dosimeters based on either biological or chemical UV dosimeters have been developed and are a powerful tool in the research on the solar UV environment. Polysulphone which has achieved wide spread use as a dosimeter in research on UV exposures resulting from the sun or artificial sources is discussed.

The risk of skin cancer, premature skin photoageing and sun-related eye disorders, including, cataracts, conjunctivitis, pterygium may be lowered by the reduction of human exposures to solar ultraviolet (UV) radiation. UV radiation is also responsible for suppression of the immune system, which in turn may lead to the development of other disorders. On the beneficial side, exposures to UV are required for the production of vitamin D. The high ambient UV levels, high personal UV exposures,¹ a predominantly fair skinned population and an emphasis on an outdoor lifestyle, contribute to Australia having the highest incidence rates of keratinocyte carcinoma

and cutaneous malignant melanoma in the world.² The cost of skin cancer to the Australian community has been estimated at \$400 million per year.² Additionally, there is the incalculable cost of the associated human suffering and disfigurement. In order to optimize the UV exposure of humans, a complete understanding of the complex solar UV environment is necessary.

UV Dosimeters

UV dosimetry based on either biological and chemical dosimeters have been developed and are a powerful tool in the research on the solar UV environment. They have been employed in research on personal solar UV exposures to humans during normal daily recreational and occupational activities and research on solar exposures in a number of different environments. In order to act as a UV dosimeter, a measurable property of these dosimeters changes in a reproducible manner due to solar UV radiation exposure. Calibration of the change against a UV recording instrument allows the use of the dosimeter for measuring UV exposures.

A category of UV dosimeters employs the effects of UV radiation on biological agents, for example dried spores of *Bacillus subtilis* to estimate the biologically harmful UV.³ The killing and mutation of the spores by UV radiation is quantified by incubation of the biofilm and measurement of the optical density at a wavelength of 590 nm. Calibration to UV radiation provides a dosimeter for measuring the biologically effective exposures for DNA damage. Another type of dosimeters contains materials that undergo photodegradation and a resulting change in optical absorbance when exposed to UV radiation. Spectrophotometers are employed to quantify the degree of degradation by measurement of the change in optical absorbance (ΔA) at a specific wavelength. Examples of different materials that have

been used as dosimeters are polysulphone, allyl diglycol carbonate (CR-39), nalidixic acid and polyphenylene oxide. Polysulphone, first proposed as a UV dosimeter by Davis et al.⁴ will be discussed further below.

Polysulphone

Polysulphone has achieved wide spread use in research on UV exposures resulting from the sun or artificial sources (for example, 1,5,6). The effectiveness of different UV minimisation strategies, for example tree shade, hats, cotton clothing, shade cloth and the timing of outdoor activities has been investigated with polysulphone dosimeters. These dosimeters have also been employed in the measurements of biologically damaging UV exposures to the surface of the eye with polysulphone fabricated into contact lenses, to the leaves of plants in greenhouses and in the field, to different depths underwater and to humans in a range of normal daily recreational and occupational activities. Examples of the population groups on which they have been employed are lawn mowing contractors, school children, construction workers, teachers, home workers, life guards, postal workers, welders and tennis players.

Exposure of the film to UV wavelengths up to approximately 340 nm causes a change in the optical absorbance (ΔA) of the film. The spectral response of 40 μm thick polysulphone film⁷ in Figure 1 is high in the UVB waveband (280 – 320 nm) and drops rapidly for wavelengths greater than approximately 320 nm. In the figure, the response of the polysulphone is normalized to unity at the most sensitive wavelength. The human skin erythema response⁸ is also shown in Figure 1 and the spectral response of the polysulphone approximates this with the differences that the polysulphone does not respond to wavelengths longer than 340 nm whereas the erythema action spectrum extends to the longer UVA wavelengths (320 - 400 nm).

Additionally, between 300 and 340 nm, the normalized response of the polysulphone is shifted to longer wavelengths by approximately 10 to 15 nm compared to the erythema action spectrum. The problem of the response of polysulphone not exactly matching the erythema action spectrum is overcome by the calibration of the polysulphone against a suitably calibrated spectroradiometer or broadband UV radiometer for the UV spectrum that it will be employed to measure.

The change in optical absorbance as a result of exposure to UV occurs at the UV wavelengths with no obvious visible influence. The maximum change in optical absorbance is at approximately 330 nm (ΔA_{330}) and this is employed to quantify the amount of photodegradation due to UV exposure and with a calibration as described below, the amount of UV exposure.

Fabrication and Calibration

The polysulphone dosimeters can be employed in a PVC holder with an overall size 3 cm x 3 cm (Figure 2) and an opening that is approximately 1.2 cm x 1.6 cm. The PVC holder is rugged and waterproof, however other forms of holders have been previously employed and are also suitable. Pieces of polysulphone of approximately 2 cm x 2 cm are attached with tape over the opening of the holder. Polysulphone film is cast at the University of Southern Queensland, Toowoomba with quality assurance of the factors influencing the UV response of the film and can be supplied in thin film or dosimeter form by the author. Factors influencing the response of the polysulphone film are thickness variations and any imperfections and irregularities on the surface of the film.

In order to prevent pre-exposure, the dosimeter fabrication is undertaken in an environment where there is no UVB component and the dosimeters are stored in the dark prior to use. Contamination of the surface is prevented by not handling the film on the 1.2 cm x 1.6 cm area that will be over the opening of the holder.

The polysulphone dosimeters are calibrated for the source spectrum that they will measure. A calibration technique for the measurement of UV exposures is to expose a series of dosimeters to different periods of UV while concurrently measuring the spectral UV irradiances with a UV spectroradiometer at set intervals and relating the ΔA_{330} to the erythral exposures to provide a calibration curve for the dosimeters. The erythral irradiances are calculated as follows:

$$UV_{ery} = \sum_{UV} S(\lambda)A(\lambda)\Delta\lambda \quad \text{W m}^{-2} \quad (1)$$

where $S(\lambda)$ is the spectral irradiance measured with the spectroradiometer, $A(\lambda)$ is the action spectrum and $\Delta\lambda$ is the wavelength increment of the measured spectral irradiance, and the summation is over the solar terrestrial UV waveband of approximately 295 nm to 400 nm. An example solar spectrum collected during a cloud free period at 8.05 am and 12.15 pm on 6 January, 2003 is shown in Figure 3. The dips in the spectrum are due to the Fraunhofer absorption lines. Alternatively, if a spectroradiometer is not available, the broadband UV irradiances can be measured at set intervals with a calibrated radiometer. Taking into account the time period between the measurements provides the erythral UV exposures in units of J m^{-2} or MED (minimal erythral dose or amount of erythral UV needed to produce erythema in type I skin 12 to 24 hours post UV exposure). Data from an example calibration is

shown in Figure 4. A cubic regression curve can be fitted to the data points to provide a calibration curve. The data shows that for the higher exposures, the polysulphone starts to saturate due to the protective filtering effect of the products of the photodegradation.

The ΔA_{330} of the polysulphone continues to change post exposure to UV even if the film is stored in the dark. This is known as the 'dark reaction.' Specifically, the ΔA_{330} measured immediately post exposure is less than that measured 24 h post exposure by about 4%.⁴ This is taken into account by allowing a constant time for all the dosimeters between exposure and read out of the post exposure optical absorbance.

Conclusion

The photodegradation of polysulphone employed in a UV film dosimeter has the principle advantages of providing a simple means of integrating UV exposures continuously and allowing numerous sites, inaccessible to bulky and expensive equipment to be compared simultaneously. The dosimeters may be attached to different anatomical sites with a clip if they are sites with clothing or alternatively with tape if the sites are not covered by clothing. Furthermore, the polysulphone is easy to handle and process and the response approximates the erythral action spectrum, providing a very useful tool for research on the UV environment.

References

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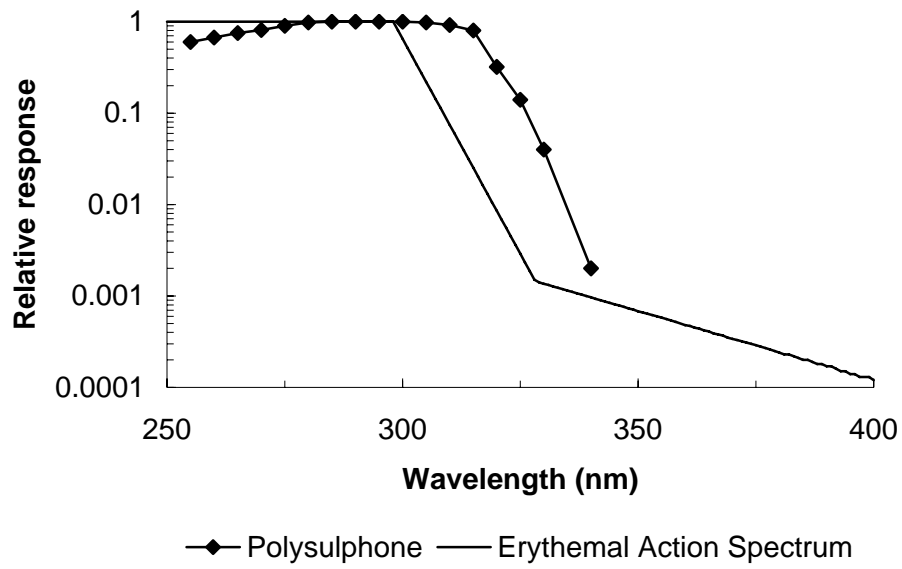


Figure 1 – Spectral response of 40 μm thick polysulphone⁷ and the erythema response of human skin.⁸



Figure 2 – Example of polysulphone dosimeters on a manikin headform.

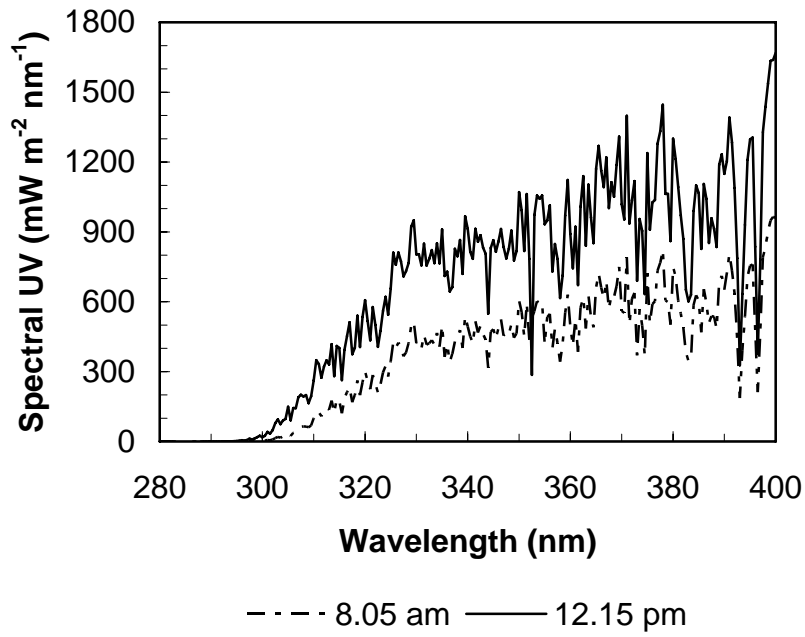


Figure 3 – Solar UV spectrum during a cloud free period at 8.05 am and 12.15 pm on 6 January 2003.

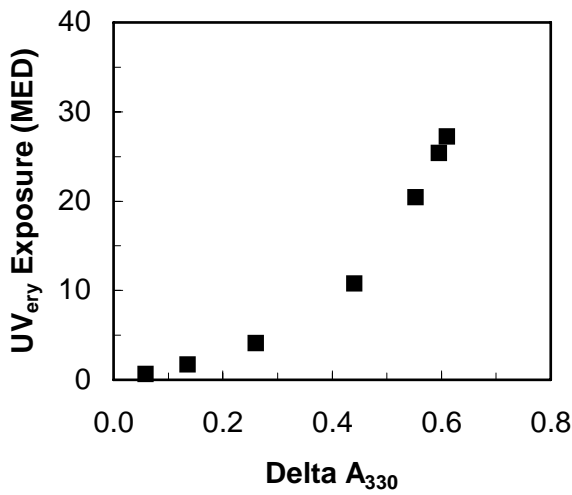


Figure 4 – Calibration of polysulphone to summer solar UV.