

USAGE OF A DOSIMETER SPECTRUM

EVALUATOR FOR DIFFERENT ENVIRONMENTS

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Abstract

The ranges of conditions and environments of a dosimetric spectrum evaluator previously developed and employed in the evaluation of the UV source spectrum have been considered in this paper. The complete system of four dosimeter materials can be employed for a total UV exposure of up to approximately 10 J cm^{-2} . The exposure times required were influenced by the UV environment. The exposure times ranged from 20 minutes to 3 hours for filtered solar erythemal UV, 5 to 30 minutes for solar erythemal UV, 30 to 53 minutes for quartz tungsten halogen lamp erythemal UV, 10 to 15 minutes for plant damage solar UV and 90 minutes for plant damage UV from fluorescent sun lamps. In these environments, employing the system in open and well-ventilated conditions minimises changes in the dose response of the system due to temperature. The results in this paper provide a guide for the range of conditions and exposure times required for different environments for future research employing the dosimetric spectrum evaluator.

INTRODUCTION

Ultraviolet (UV) radiation is a genotoxic and has a causative role in human skin cancer, premature skin photo-aging and wrinkling and some eye disorders (Longstreth et al., 1995). Additionally, increased ultraviolet irradiances due to stratospheric ozone depletion may affect plant growth (Caldwell et al., 1995). An improved characterisation and understanding through UV measurements of the solar UV exposures to humans and plants is required.

The measurement of UV radiation in photobiological experiments has been reviewed in another paper (Wong and Parisi, 1998). Spectroradiometers and radiometers may be employed for ambient UV measurements on a horizontal plane. However, UV dosimeters must be employed for simultaneous multi-site measurements of the UV irradiances to specific sites on the object of study. Dosimeters based on polysulphone (Diffey, 1989) and CR-39 (Wong et al., 1992) have been employed for erythemal UV measurements. A dosimetric spectrum evaluator based on four different UV dosimeter materials has been developed (Parisi et al., 1997, Parisi and Wong, 1996a) and employed in photobiological research (for example, Parisi et al., 1998a). Each of the materials is sensitive to different UV wavelengths and measurement of the change in the optical absorbance of each of the materials at a set wavelength for each material allows broad scale evaluation of the UV spectrum. The minimum irradiance required on this type of detector is $0.01 \mu\text{W cm}^{-2}$. This paper investigates the range of conditions and exposure times of the spectrum evaluator system for different UV environments.

MATERIALS AND METHODS

Dosimeter System

The technique for the spectrum evaluator based on the four different dosimeter materials, polysulphone, nalidixic acid, 8-methoxypsoralen and phenothiazine has been described elsewhere (Parisi et al., 1997). The physical size of the spectrum evaluator holder is approximately 3 cm x 3 cm. Each different material is over a 0.6 cm diameter hole in the holder. The four different materials employed in the spectrum evaluator have different responses to UV radiation. Consequently, they provide measurements of the exposures in the respective wavebands. As a combined system, the four exposure measurements allow broad scale reconstruction of the source spectrum.

The system provides the time averaged spectrum over the exposure period and incorporates any changes in the source UV spectrum during the period. The evaluated source spectrum agrees to better than 20% with that measured with a calibrated spectroradiometer. The exposure times for the spectrum evaluator are a compromise between a sufficient UV exposure to produce a measurable change in optical absorbance of the material, but not long enough to either saturate the most sensitive dosimeter material or allow an unacceptable large change in the source spectrum.

Environments

The spectrum evaluator has been employed to evaluate the UV spectrum for both natural and artificial UV sources at any orientation over the object of study in a number of environments. The system has been employed to measure the biologically effective UV irradiances received to specific body sites on humans and on a

horizontal plane in a number of different environments, namely, in a car interior (Parisi and Wong, 1998), glass enclosure (Parisi and Wong, 1997a) and greenhouse (Parisi and Wong, 1997b) for solar UV, outside for winter and summer sun and in the laboratory employing a quartz tungsten halogen (QTH) lamp (Parisi et al., 1997) as the UV source. For plant studies, the system has been employed over a plant canopy, both in the field (Parisi and Wong, 1996b, Parisi et al., 1998b) and in a greenhouse (Parisi et al., 1996). In the greenhouse, artificial UV was provided with Philips TL40/12 sunlamps. The effect of ambient air temperature in each of these environments on the response of the dosimeter material is also discussed.

Following the evaluation of the source spectrum, S_λ , with the spectrum evaluator, the biologically effective UV irradiance (UVBE) can be calculated for any action spectrum, A_λ , for the particular biological process under investigation. Alternatively, the unweighted broadband UV irradiances may be calculated from the knowledge of the source spectrum. The biologically effective UV irradiance for any action spectrum is calculated as follows:

$$\text{UVBE} = \int_{\text{uv}} S_\lambda A_\lambda d\lambda \quad (1)$$

where the integration is over the UV wavelengths. In this paper, the action spectrum for human erythema (CIE, 1987) and the generalised plant damage action spectrum (Caldwell, 1971) are employed.

RESULTS

Saturation

The dose response to UV radiation of each of the dosimeter materials has been measured (Parisi and Wong, 1996a). The approximate total UV exposure for which

the dose response of each of the materials starts to saturate is provided in Table 1. Phenothiazine is the most sensitive of the four materials with 8-methoxypsoralen the least sensitive. Phenothiazine saturates for total UV exposure of approximately 10 J cm^{-2} , whereas, 8-methoxypsoralen has a linear dose response for a total UV exposure of up to 40 J cm^{-2} . Similarly, nalidixic acid and polysulphone have an approximate linear response to about 15 J cm^{-2} of total UV before the response starts to saturate. These are the approximate exposure limits before the individual dosimeters start to saturate. As a combined system of dosimeters, the exposure limit for the system is approximately 10 J cm^{-2} .

Table 1 - The approximate total UV exposure at which the dose response of each of the materials start to saturate.

Material	Total UV exposure (J cm^{-2})
Phenothiazine	10
Nalidixic acid	15
Polysulphone	15
8-methoxypsoralen	40

Environments

The different environments in which the spectrum evaluator has been employed and the range of biologically effective irradiances for human erythema and generalised plant damage that have been encountered are provided in Table 2. The environments can be divided into a number of categories. Namely, filtered solar UV in a greenhouse, glass enclosure and a car interior with erythemal irradiances ranging

from 0.01 to 0.93 $\mu\text{W cm}^{-2}$. The spectrum evaluator has been orientated at the appropriate angles both over a rectangular prism and a manikin to approximate the human body shape. The second category of environment was solar UV for both summer and winter with the spectrum evaluator attached to human volunteers and erythemal irradiances of 3.1 to 25 $\mu\text{W cm}^{-2}$. The third category was for UV from a QTH lamp in the laboratory on a horizontal plane with irradiances of 18 to 43 $\mu\text{W cm}^{-2}$. For plants, the irradiances can be grouped into natural sunlight in winter and autumn and artificial UV provided with sunlamps in a greenhouse. For sunlight, the plant damage irradiances were 9 to 17 $\mu\text{W cm}^{-2}$ and 10 to 43 $\mu\text{W cm}^{-2}$ in winter and autumn respectively with plant damage irradiances of 2 to 20 $\mu\text{W cm}^{-2}$ in the greenhouse.

Table 2 - The range of different environments and the biologically effective irradiances for which the spectrum evaluator has been employed.

Object	Environment	Source	UVBE ($\mu\text{W cm}^{-2}$)
Human model	Greenhouse	Spring Sun	0.06 - 0.32
Human model	Glass enclosure	Sun	0.18 - 0.93
Human model	Car interior	Winter Sun	0.01 - 0.14
Humans	Winter	Sun	3.1 - 4.2
Humans	Summer	Sun	17 - 25
Horizontal Plane	Laboratory	QTH lamp @ 10 cm	43
Horizontal Plane	Laboratory	QTH lamp @ 14 cm	18
Plants	Winter	Sun	9 - 17
Plant model	Autumn	Sun	10 - 43
Plants	Greenhouse	Sunlamps	2 - 20

Exposure Times

For general applications, the ranges of exposure times employed for the spectrum evaluator for the different irradiances and environments are provided in Table 3. The exposure times ranged from 20 minutes to 3 hours for the filtered solar erythemal UV, 5 to 30 minutes for the solar erythemal UV, 30 to 53 minutes for the QTH lamp

erythemal UV, 10 to 15 minutes for the plant damage solar UV and 90 minutes for the plant damage lamp UV.

Table 3 – The range of biologically effective irradiances for erythema^(a) and plant damage^(b) and the approximate exposure times that may be employed.

UV Source	UVBE ($\mu\text{W cm}^{-2}$)	Exposure Time (minutes)
Filtered solar UV	0.06 – 0.32 ^(a)	60
Filtered solar UV	0.18 – 0.93 ^(a)	20
Filtered solar UV	0.01 – 0.14 ^(a)	180
Solar UV	3.1 – 4.2 ^(a)	30
Solar UV	17 – 25 ^(a)	5
QTH lamp	43 ^(a)	30
QTH lamp	18 ^(a)	53
Fluorescent sunlamps	2 – 20 ^(b)	90
Autumn sun	10 – 43 ^(b)	10
Winter sun	9 – 17 ^(b)	15

Temperature

The effects of temperature on the individual dosimeter materials have been measured over the temperature range 34.5 to 61.3 °C (Parisi and Wong, 1996a). Over this range, there was no significant temperature effect for polysulphone and 8-methoxypsoralen and phenothiazine showing no effect up to 50 °C, with an effect for higher temperatures. For nalidixic acid, there was a small increase with temperature in the change in absorbance of 0.001 /°C. As a combined system of dosimeters, any

temperature effects can be minimised by using the system at approximately constant temperatures below 50 °C. These can be maintained by employing the system in the open or well-ventilated conditions.

CONCLUSION AND DISCUSSION

The ranges of conditions and environments of a dosimetric spectrum evaluator previously developed and employed in the evaluation of the UV source spectrum have been considered in this paper. The complete system of four dosimeter materials can be employed for a total UV exposure of up to approximately 10 J cm⁻². For the different environments, the exposure times required for the spectrum evaluator were found to be a compromise between producing a measurable change in optical absorbance of the dosimeter material and reducing the saturation of the dosimeter material and minimising any changes in the source spectrum. The exposure times ranged from 5 minutes to 3 hours and were dependent on the UV irradiances and the general shape of the UV spectrum, which was influenced by the UV environment. In these environments, employing the system in open or well-ventilated conditions up to temperatures of 50 °C minimises changes in the dose response of the system due to temperature. The results presented in this paper provide a guide for the ranges of conditions and exposure times required for the different environments for future research employing the dosimetric spectrum evaluator.

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