HUMAN EXPOSURE TO FILTERED SOLAR ULTRAVIOLET RADIATION

A.V. Parisi[1] and J.C.F. Wong[2]

[1]Centre for Astronomy and Atmospheric Research, University of Southern Queensland, Toowoomba, 4350, Australia. Ph: 61 76 312226. FAX: 61 76 312721. Email: parisi@usq.edu.au

[2]Centre for Medical and Health Physics, Queensland University of Technology, GPO Box 2434, Brisbane 4001, Australia. Ph: 61 7 38642585. FAX: 61 7 38641521.

Abstract

The erythemal exposure due to filtered ultraviolet radiation has been evaluated with a dosimetric spectrum evaluator in a glass enclosure to simulate a sun-room with glass roof and walls, in a greenhouse and in a small and large car. The ratio expressed as a percent of the erythemal irradiances to the shoulder of a person in an upright position inside each of the environments to those measured outside the enclosures were 5 to 7%, 1%, 1.2% and 0.7%. The average of the erythemal exposures to the facial sites over a six hour period were 0.05 MED and 0.02 MED for the small and large car respectively. Although the exposure was a fraction of an MED, the cumulative exposure received by humans in the above enclosures in a fortnight is of the same order of magnitude as that received during periodic leisure activities in the outdoor environment.

Introduction

Approximately 800 Australians die annually from melanoma and 200 annually from non-melanoma skin cancer (NMSC) (Foot et al., 1993). Skin cancer is estimated to cost the Australian community an estimated $400 million per year (Girgis et al., 1994). Additionally, there is the human suffering costs. Queensland, Australia due to its low latitudes and relatively clear skies has high levels of ambient solar UV radiation (280-400 nm) and has the highest incidence rates of NMSC and cutaneous malignant melanoma in the world (Lowe et al., 1993). Ultraviolet radiation exposure has a causative role in human skin cancer (Longstreth et al., 1995).

The damaging effect of UV radiation on human skin can be expressed employing the human erythemal action spectrum in Figure 1 (CIE, 1987) to calculate the biologically effective UV irradiance (UVBE) as follows:

$$UVBE = \int_{280}^{400} S(\lambda)A(\lambda)d\lambda \qquad \mu\text{W cm}^{-2} \qquad (1)$$

where S(λ) is the source spectrum and A(λ) is the erythemal action spectrum. Figure 1 shows the erythemal response of human skin (CIE, 1987) with the value of the sensitivity dropping by about 3 decades for the UVB waveband (290-320 nm). In the UVA waveband (320-400 nm), the value of the action spectrum varies from 10^{-3} to 10^{-4}. Thus the damage caused by the UVB band of radiation is far more important than that caused by the UVA band.

Transparent screens such as glass and automobile windscreens and window glass act as a barrier to some of the shorter solar ultraviolet radiation wavelengths (Gies et al., 1992, Parisi and Wong, 1997) and as a result can provide a degree of protection to humans. Although filtered solar ultraviolet radiation is predominantly in the UVA band, its harmful effect is not to be under-estimated because of the high level of irradiance. Recent research (Lavker et al., 1995) has shown that repetitive exposures to relatively low UVBE due to UVA wavelengths has a cumulative effect and can produce skin alterations indicative of early tissue damage. Sutherland et al. (1991) found that UVA exposure can induce pyrimidine dimers and as a result can cause DNA damage in human skin.

Human exposure to solar UVB and ambient solar UVB have been measured by a number of authors using polysulphone dosimeters (Wong et al., 1996, Gies et al., 1995) and Robertson-Berger meters (Scotto et al., 1988). These detectors do not have a significant response in the UVA waveband (Figure 1). This paper presents a recently developed method based on a dosimetric technique of evaluating the UVA spectrum to allow calculation of the biologically effective UV for the particular action spectrum. Development and testing of the method has been described elsewhere (Parisi et al., 1996, Parisi et al., 1997, Wong and Parisi, 1996). The erythemal UV due to filtered solar UV radiation in a glass enclosure to simulate a sun-room with glass roof and walls, in a greenhouse and in two cars will be compared.

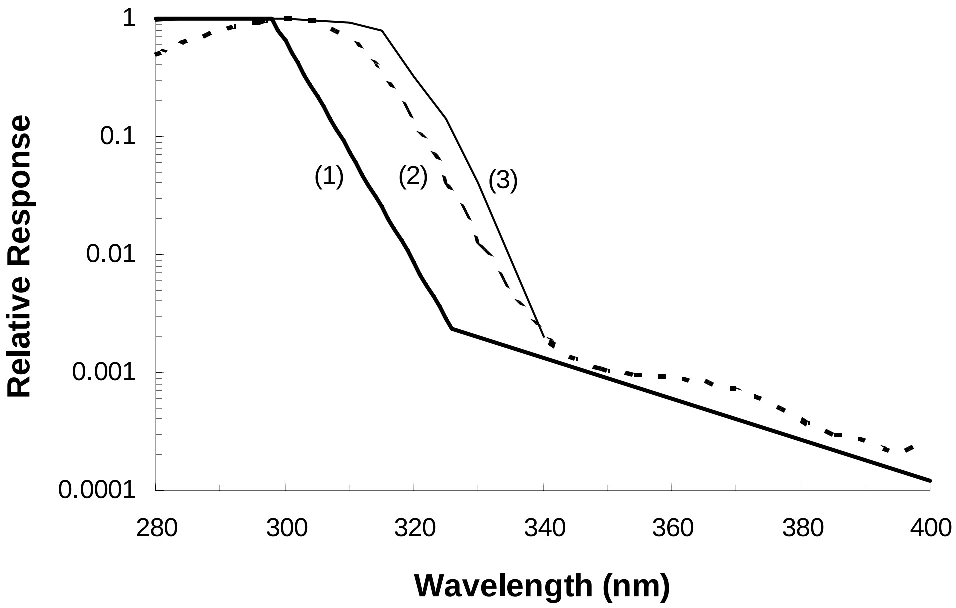

Figure 1 - (1) The erythemal action spectrum for humans (CIE, 1987), (2) relative response of the Robertson-Berger meter (DeLuisi et al., 1992) and (3) relative response of polysulphone film (CIE, 1992).

Materials and Methods

Spectrum Evaluation

A recently developed UV spectrum evaluator, (Wong and Parisi, 1996) with four types of UV sensitive dosimeter films was employed for evaluation of the filtered solar ultraviolet spectrum. The dosimeter materials employed in the spectrum evaluator are polysulphone, nalidixic acid (NDA), 8-methoxypsoralen (8MOP) and phenothiazine (Parisi et al., 1997). A piece of the material of approximately 1 cm^2 was placed over a 0.6 cm diameter hole in a holder with an overall size of 3 cm x 3 cm in the form of a film badge. The materials change their optical absorbance after exposure to ultraviolet radiation. This was determined for each material by measuring the absorbance at 330 nm for both polysulphone and NDA, 305 nm for 8MOP and 280 nm for phenothiazine before and after exposure in a spectrophotometer

(Shimadzu Co., Kyoto, Japan). The post-exposure absorbance was measured as soon as practical following the exposure.

Each type of film is responsive to different UV wavebands (Wong and Parisi, 1996). The result of the change of absorbance in these films caused by the exposure to solar radiation was used to evaluate the UV source spectral irradiance applied to the device (Parisi et al., 1997). The spectral irradiance was used to calculate the erythemally effective irradiance using Equation (1). The change in absorbance in the dosimeter materials is a result of the total integrated exposure over the period. As a result, the spectrum evaluated is the time averaged spectrum over the period. Unlike the popular UV dosimeter such as polysulphone, this device has a significant sensitivity over the entire range of UV wavelengths. For measurements of glass filtered solar UV radiation, a horizontal spectrum evaluator requires approximately 20 minutes exposure in the midday sun (ambient irradiance 7 to 24 $\mu W\ cm^{-2}$) to produce a measurable change in the detectors.

Filtered Solar UV

The filtered solar UV irradiances were measured in Toowoomba, (27.5^o S latitude) Australia between 4 September, 1996 and 25 August, 1997. The filtered UV exposures to a horizontal plane and to four vertical planes orientated to each of 0^o, 90^o, 180^o and 270^o of azimuth angle from north in a glass enclosure to simulate a sun-room with glass roof and walls and in a greenhouse were measured using UV spectrum evaluators. Three sites at the eastern side, centre and western side of the greenhouse were simultaneously measured. A car from the small class and a car from the large family class were employed with the spectrum evaluators deployed at body sites over a manikin in each of the drivers seats. Both cars had the windows fully wound up with the manufacturer's tint on the windows of the large car and no tint on the small car windows.

For the glass enclosure the spectrum was evaluated at three exposure times, namely, 9.00 to 9.20 Australian Eastern Standard Time (EST), 11.50 to 12.10 EST and 14.40 to 15.00 EST. The exposure times for the greenhouse were 9.00 to 10.00 EST, 11.30 to 12.30 EST and 14.00 to 15.00 EST and for the cars they were 9.00 to 12.00 EST and 12.00 to 15.00 EST. In each case, the length of the exposure times was chosen as a compromise between a sufficient exposure to produce a measurable change in absorbance in each of the four materials and not too long so that there was not a saturation of the response in any of the dosimeter materials. The unfiltered erythemal UV on a horizontal plane was measured outside each enclosure at the start, middle and end of the six hour period with a meter (Model 3D V2.0, Solar Light Co., Philadelphia, USA).

Typical Scenarios

The erythemal exposure due to filtered solar UV to humans in three hypothetical scenarios at the latitude of the measurements in this paper were estimated. It was assumed that no personal sun protection measures such as hats or sunscreens were implemented. It was also assumed that the daily exposure remained approximately unchanged over the period of a fortnight. The scenarios considered were:

A. The erythemal UV exposure to the upper arm of a farmer in the glass cabin of his tractor planting, cultivating or harvesting the winter crop for 6 hr/day for 12 days per fortnight compared to the erythemal UV exposure to the shoulder of a spectator in the open at a winter sport such as football for 1 hr per fortnight.
B. The erythemal UV to the shoulder of a worker in a greenhouse in summer for 6 hr/day for 12 days per fortnight compared to a visit to the beach in summer of 1 hr per fortnight.
C. The erythemal UV to the shoulder of a person relaxing in a sunroom in spring for 1 hr/day for 14 days per fortnight compared to spring gardening of 1 hr per fortnight.

For all three scenarios, the exposures to the shoulder of the spectator, beach-goer and gardener were taken as the erythemal exposure measured outside the enclosures on a horizontal plane with the meter.

Results and Discussion

Filtered Irradiances

The erythemal exposures for the six hour periods to the horizontal and vertical surfaces between 9.00 and 15.00 EST in a glass enclosure, a greenhouse, a small car and a large car are provided in Table 1. The unfiltered erythemal UV on a horizontal plane over a six hour period measured outside each enclosure are also provided. The erythemal exposures were converted to units of a minimum erythemal dose (MED) where one MED is defined as 20 mJ cm^{-2} (Diffey, 1992) and is the amount of biologically effective UV required to produce barely perceptible erythema after an interval of 8 to 24 hours following exposure. The erythemal exposures, particularly, the lower ones in the greenhouse and in the small and large cars are too low to be measured with a Robertson-Berger meter. Whereas, with the spectrum evaluator, the exposure time was lengthened for these lower exposures to record the cumulative effect. For the glass enclosure and greenhouse the exposures in the row called vertical are the average of the exposures to the four vertical orientations, namely, 0^o, 90^o, 180^o and 270^o of azimuth angle from north and for the small and large cars, the horizontal and vertical orientations are the right hand and right upper arm sites respectively.

Table 1 - The unfiltered solar erythemal UV on a horizontal plane and the erythemal exposures due to filtered solar UV radiation over a six hour period in a glass enclosure, a greenhouse, a small car and a large car. For the small and large cars, the horizontal and vertical orientations are the right hand and right upper arm sites respectively.

	Erythemal Exposures (MED) over a six hour period					
	Glass Enclosure		Greenhouse		Small car	Large car
	4 Sept 96	18 Oct 96	28 Nov 96	5 Feb 97	25 Aug 97	25 Aug 97
Ambient	11.6	18.1	18.7	22.4	10.5	10.5
Horizontal	0.85	0.89	0.25	0.25	0.13 (r. hand)	0.07 (r. hand)
Vertical	0.38	0.44	0.11	0.12	0.16 (r. up. arm)	0.07 (r. up. arm)

In order to compare the erythemal exposures in each environment, the ratios of the filtered irradiances to the erythemal irradiances measured outside the enclosures are provided as a percentage in Table 2. Relative to irradiances measured outside the environments, the inside of the glass enclosure received the highest irradiances of the enclosures to both the horizontal and vertical planes. The relative irradiances to the right hand of the manikin in the small car were approximately the same as those in a horizontal plane in the greenhouse. In comparison, due to the manufacturer's window tint on the large car, the right hand of the manikin in the small car received approximately 1.7 times more than that in the large car. The vertical surface of the right upper arm in the small car received more than the exposure on the horizontal surface of the right hand due to the proximity of the upper arm to the side window glass. There is no difference between the two sites for the large car, again as a result of the tint.

Table 2 - Ratios expressed as a percent of the erythemal irradiances inside each of the environments to those measured outside the enclosures.

	Filtered/Ambient (%)			
	Glass Enclosure	Greenhouse	Small car	Large car
Horizontal	5 - 7	1	1.2	0.7
Vertical	2 - 4	0.5 - 0.6	1.5	0.7

The average of the erythemal exposures measured at four sites on the face of the manikins over the six hour exposure period in the small and the large cars are in Table 3. For the small car, the exposure to the face is reduced by a factor of 210 compared to the ambient exposures outside on a horizontal plane. For the large car, the exposures are reduced by a factor of 525.

Table 3 - Erythemal exposures to the face.

Enclosure	Facial Exposure (MED)	Ambient (MED)
Small car	0.05	10.5
Large car	0.02	10.5

In Table 4, the erythemal exposures in each environment have been employed to determine the time required to produce an exposure of 1 MED for each environment. For the horizontal plane, this is 6.7 to 7.1 hours for the glass enclosure compared to 24 hours for the greenhouse, 46 hours for the small car and 86 hours for the large car. This difference is due predominantly to the additional shading provided by the shadecloth on the top of the greenhouse roof glass and by the protection provided by the top of the cars and by the manufacturer's tinting on the window glass of the large car.

Table 4 - Time in hours required to produce an exposure of 1 MED in each of the enclosures.

	Time (Hours)					
	Glass Enclosure		Greenhouse		Small car	Large car
	4 Sept 96	18 Oct 96	28 Nov 96	5 Feb 97	25 Aug 97	25 Aug 97
Horizontal	7.1	6.7	24	24	46	86
Vertical	16	14	55	50	38	86

Typical Scenarios

The filtered and unfiltered exposures in Table 1 have been employed to provide in Table 5 a comparison of the filtered erythemal exposures received in three hypothetical scenarios. The type of activities are listed in the second column and the fourth column. The third column provides the result of the exposure due to filtered radiation and the fifth column gives the result of outdoor exposure. In scenario A, the exposures to the right upper arm in the small car in winter were taken as an estimate of the exposure to the right upper arm of a farmer in a tractor cabin during winter. In a fortnight, the farmer received an exposure to the right upper arm of the same order as that to the shoulder of a spectator at a winter sport for 1 hr/fortnight. For each day in the fortnight, the exposure to the shoulder of the worker in the greenhouse in scenario B was taken as the average of the exposures to the horizontal plane on both measurement dates for the greenhouse in Table 1. The exposure to the shoulder of the beach-goer was estimated as the average of the exposures on the two dates to the horizontal plane outside the enclosure in Table 1. In a fortnight, the worker received an exposure of the same order as that received to the shoulder in a summer beach visit of 1 hr/fortnight. In scenario C, the exposure in one hour each day to the shoulder of a person relaxing in the sunroom was estimated as one sixth of the average exposures on the two measurement dates received in the six hour exposure in the glass enclosure in Table 1. The exposure to the shoulder of the gardener was estimated as the average of the exposures on the two dates to the horizontal plane outside the enclosure. The person in the sunroom received an exposure of the same order as that to the shoulder of a person gardening in spring for 1 hr/fortnight.

Table 5 - Comparison of erythemal UV exposure in different scenarios.

Scen-ario	Activity in Protected Environment	UVBE (MED)	Outdoor Activity	UVBE (MED)
A.	Farmer in cabin of tractor - winter (6 hr/day for 12 days/fn)	1.9	Spectator at winter sport (1 hr/fn)	1.7
B.	Worker in greenhouse - summer (6 hr/day for 12 days/fn)	3.0	Summer beach visit (1 hr/fn)	3.4
C.	Relaxing in sunroom - spring (1 hr/day for 14 days/fn)	2.0	Spring gardening (1 hr/fn)	2.5

Conclusion

Although the level of UVB radiation can be reduced substantially by various types of barriers such as plastic and glass, UVA radiation can penetrate through these materials. As a result, exposures to erythemal solar radiation can be incurred under the protection of UVB barriers. On the measurement dates, the inside of the glass enclosure received the largest amount of erythemal UV radiation of the four environments. Relative to the erythemal exposures outside the environments, the interior of the glass enclosure on a horizontal plane received approximately 5 to 7 times more than the inside of the greenhouse, the exposure to the right hand in the small car was of the same order to that on a horizontal plane in the greenhouse and approximately 1.7 times more than the exposure to the right hand in the large car.

The cumulative exposure to filtered erythemal UV radiation over a two week period to a farmer in a tractor cabin, a worker in a greenhouse and a person relaxing in a glass sunroom were respectively of the same order of magnitude as the cumulative exposure to unfiltered erythemal UV radiation received in a one hour period by a spectator at an outdoor sport, a person at the beach and a gardener. The cumulative erythemal UV exposure received over a period due to filtered solar radiation may be as high as that received during periodic leisure activities. With the publicity and education campaigns on sun exposure, the general population may be more aware of the dangers of UV radiation at the beach, at a sportsground or in the garden and take appropriate protective measures. However, the general population may underestimate or not be aware of the erythemal UV due to filtered UV received in an enclosure and as a result not take any protective measures.

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