UVR PROTECTION OFFERED BY SHADECLOTHS AND POLYCARBONATES*

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Abstract

Measurements of the transmission characteristics of various shadecloth and polycarbonate materials in the visible and ultraviolet spectral regions can be used to determine the biologically effective protection provided against solar ultraviolet radiation. The results show a strong linear association between the mean visible and ultraviolet spectral transmittance for most types of shadecloth examined. The calculated biologically effective protection factor for shade cloth is dependent on weave construction with closely woven fabric providing higher protection than loosely woven fabric. The ultraviolet exposure received by a person beneath a shade structure is influenced by factors other than the transmittance of the covering material, and these are discussed.

Introduction

Australia has the highest incidence rate for both non-melanoma skin cancer and cutaneous melanoma in the world. The reason skin cancer incidence rates are higher in Australia is due to a combination of factors. Firstly, Australia has higher ambient levels of solar ultraviolet radiation (UVR) in comparison with Europe and North America. In addition, the population of Australia comprises mainly of fair-skinned people who enjoy an outdoor lifestyle, and thus have high UVR exposures. It is only in more recent years that Australians have begun to take adequate precautions to reduce their exposure to the high levels of ambient solar UVR.

Over-exposure to solar UVR causes erythema and irreversible skin damage, such as skin ageing and skin cancer. Erythema, commonly known as sunburn, occurs on anatomical sites exposed to UVR and the severity of erythema increases with exposure. Skin cancers can develop on people who do not have a history of severe sunburn. Non-melanocytic skin cancers are prevalent on anatomical sites of greatest exposure to UVR, particularly the head, neck and arms[1]. In contrast, malignant melanoma occurs on sites that are intermittently exposed to sunlight, and is most common on the backs of men and legs of women[2]. The work of Holman et al.[3] suggests that some types of malignant melanoma are unrelated to sunburn history. The high incidence of skin cancer in Australia can be reduced providing the public adopt the protection practices outlined in the educational campaigns of the various state cancer councils.

Various items can be used for personal protection against solar UVR, such as hats, sunglasses, clothing and topically applied sunscreens. On a community scale, some councils in Australia provide sun shelters for use in public places. These shade structures are positioned in parks, recreation areas, swimming centres and public transport stops. Materials that can be used for shelter, consist of vegetation, shadecloth, polycarbonate sheeting and standard opaque building materials.

Shadecloth and polycarbonate sheeting are synthetic materials whose purpose is to moderate the amount of sunlight entering a particular environment[4]. The transmission of solar radiation through shadecloth is dependent on tightness of the weave and its gauge, with closer weaves providing greater protection against sunlight. The fibres of the textile absorb and scatter incident radiation reducing the amount of sunlight transmitted.

Shadecloths are available in either closely woven or mesh materials. The mesh is constructed from plastic fibres knitted or woven into pliant planar sheets. Meshed materials transmit filtered sunlight into greenhouses and pergolas while maintaining sufficient air circulation within the shaded area. The term 'horticultural' will be used to represent mesh structured materials. The size of the openings within the mesh influences the amount of sunlight transmitted through the material. Horticultural shadecloths transmit between 10% and 50% of the incident visible and ultraviolet wavelengths into the shaded area. The outdoor performance requirements for horticultural shade cloth are specified in Australian Standard AS4174[4].

Closely woven fabrics cast a denser shadow than horticultural cloths. The deeper the shade cast by a shadecloth the greater the protection it offers against sunlight. Umbrella and awning fabrics are examples of closely woven materials. However, these fabrics will photodegrade after prolonged exposure to solar UVR.

Polycarbonate sheeting is manufactured in various clear or tinted profiles. The main purpose of the sheeting is to weatherproof an outdoor area while maintaining adequate visible light levels within the sheltered region. The thickness, tint and profile of polycarbonate sheeting influences the visible transmittance of the material. Ultraviolet radiation can cause embrittlement and discolouration in polycarbonate sheeting by photo-oxidative degradation[5]. Adding a photostabiliser to polycarbonate materials extends the lifetime of the product in the severe Australian climate. However, Davis[6] stated that it is difficult to determine how long a material will last in a particular environment as the deterioration of polymer materials is a complex process. The rate of photo-oxidation of any polymer is dependent on a combination of the following[6]: characteristics of the material, UV exposure, angle of exposure, ambient temperature, and moisture.

The effective protection offered by various shadecloths and polycarbonate materials have been investigated at the

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Australian Radiation Laboratory, and a method for categorising the UVR protection of the material has been developed[7].

Experimental Method

A spectroradiometer was used to measure the spectral transmittances of a variety of shadecloths across the 290 to 400 nm wavelength range in 5 nm increments. The instrument consists of a Spex 1680 double monochromator (DM) having a 100-mm diameter barium sulphate coated integrating sphere as the input optics, and an EMI 9635QB photomultiplier as the detector at the exit slit.

An Oriel 300 Watt solar simulator was used as the irradiance source. The lamp emission was given at least 15 minutes to stabilise before the measurements commenced.

A scan of the unobstructed solar simulator irradiance was recorded using the spectroradiometer. The measurement was repeated with the test material positioned over the entrance aperture of the integrating sphere. The integrating sphere collects and spatially averages the transmitted and forward scattered radiation. The spectral transmittance was then calculated from a ratio of the measurements recorded with and without the sample in place.

The transmittance measurements were repeated for each sample across the 250—800 nm wavelength range with a Varian DMS90 UV-Visible spectrophotometer. These measurements are compared with the results from the spectroradiometer. The spectrophotometer results are of transmitted radiation only, and are generally lower than the values recorded with the spectroradiometer. The spectral transmittances of polycarbonate sheeting were determined using the spectrophotometer as dispersion of the transmitted radiation is minimal. All measurements were recorded with the incident radiation normal to the material.

Due to the educational campaigns of the various state cancer councils the Australian public are familiar with the sun protection factor (SPF) rating of sunscreens. However, the public would have difficulty evaluating the protection provided by a product labelled with an ultraviolet transmittance value. Consequently, a rating scheme was developed to quantify the degree of protection offered by a variety of personal and commercial items, and is similar to the SPF rating of sunscreens[7]. The calculation method of Gies et al.[7] is used throughout this work to determine the protection factors for shadecloth and polycarbonate sheeting. The difference between the respective rating schemes is that SPF is determined from 'in vivo' evaluation techniques and the protection factors of Gies et al.[7] from 'in vitro' methods.

The protection factor, PF, is calculated by comparing the photobiologically effective irradiance without and with the test material in place, as follows:

$$\mathrm{PF} = \frac{\Sigma\, E_\lambda S_\lambda \Delta_\lambda}{\Sigma\, E_\lambda S_\lambda T_\lambda \Delta_\lambda}$$

where:
E_λ is the solar UVR spectral irradiance in $\mathrm{W.m^{-2}.nm^{-1}}$,
S_λ is the CIE erythemal spectral effectiveness,
T_λ is the spectral transmittance,
Δ_λ is the bandwidth in nm and
λ is the wavelength in nm.

The effective irradiance is determined by weighting a solar spectral power distribution with the CIE action spectrum for erythema[8], and summing over all wavelengths responsible for initiating the biological effect. Weighting with the action spectrum is necessary as the skin does not respond to all ultraviolet wavelengths equally, and the wavelengths responsible for inducing erythema are given greater significance in the calculation. The summation is possible under the assumption that the radiant exposure at each wavelength is independent of other wavelengths[9]. Repeating the calculation with the spectral transmittance determines the effective irradiance transmitted through the material. The protection factor is more meaningful than UVR transmittance as it indicates the degree of effective protection offered by the material.

Results and Discussion

A. Shadecloth

A summary of the transmittance measurements of some horticultural shadecloths is given in Table 1, and Table 2 displays the results for canvas and parasol materials. Each table lists the type, colour, mean transmittance in the UVB (280 to 315 nm), UVA (315 to 400 nm) and visible (400 to 770 nm) spectral regions for each shade cloth, and its corresponding protection factor against ultraviolet radiation. Percentage transmittances for the UVB and UVA with the respective protection factor were determined from the spectroradiometric measurements, and the visible transmittance was obtained from the spectrophotometer data. The results show that canvas materials have larger protection factors than horticultural cloths as there are few open spaces in the weave. Protection factors for canvas are over 50, which is higher than most clothing fabrics and the 15+ maximum of sunscreens, while horticultural textiles usually have factors less than 10.

The ultraviolet transmittance spectrum was virtually flat for each of the horticultural cloths evaluated. Figure 1 displays typical ultraviolet and visible transmittance spectra for horticultural cloths. The flat spectrum for the black coloured shadecloth shows that the transmission is independent of wavelength. This wavelength independence suggests that optical radiation is directly transmitted and scattered through the interstices and does not penetrate through the yarns of the cloth[10].

Not all shadecloths exhibited flat visible transmittance spectra. Some shadecloths had a higher throughput in the visible wave band with the maximum coinciding with the colour of the textile. Green and blue coloured cloths in Figure 1 show this effect. The fibres of the green material, for example, absorb all wavelengths of light except green. The green light transmitted by the fibres recombines with that from the interstices to produce the transmittance peak. At wavelengths away from the colour of the material the spectrum is relatively flat suggesting that only the open spaces in the weave transmit optical radiation. A maximum in the transmittance spectrum occurred with some coloured horticultural cloths.

Figure 2 compares the mean ultraviolet transmittance of horticultural shadecloth measured using the spectrophotometer and the spectroradiometer. Regression analysis of the data in Figure 2 gives a line of best fit of 0.94 ± 0.03 and intercept of 0.7%. The good agreement results from the high transmittance associated with

Table 1

Mean spectral transmittance and protection factor of some horticultural shadecloths.

Material	Tuvb[1]	Tuva[2]	Tvis[3]	PF4
HORTICULTURAL				
Green 50%	42.6	42.8	41.5	2.4
Sandstone 50%	38.6	41.3	43.4	2.5
Toffee 50%	37.3	37.7	34.8	2.7
Forestgreen 50%	38.2	38.7	34.5	2.5
Green 70%	41.3	40.4	37.9	2.2
Sandstone 70%	32.5	33.0	30.9	3.1
Toffee 70%	30.2	30.4	26.6	3.3
Forestgreen 70%	25.4	25.2	25.6	3.9
Black 70%	40.2	39.1	41.5	2.2
Biscuit 70%	44.3	44.5	42.3	2.0
Jacaranda 70%	42.8	43.3	42.7	2.1
Seagreen 70%	31.0	32.1	30.0	3.2
Peach 70%	31.3	31.8	26.2	3.2
Iceblue 70%	27.5	28.2	23.4	3.6
Black 75/80%	21.9	21.3	21.0	4.6
White 75/80%	27.6	28.6	25.0	3.5
White/Blue 80%	12.1	13.4	11.4	8.3
White/Green 80%	14.8	15.7	14.7	6.8
Eucalypt 90%	8.0	9.2	5.1	11.0
Heritage Green 90%	14.2	14.4	13.6	6.3
Champagne/Sage 90%	11.5	12.2	8.2	8.2
Black 90%	6.4	6.1	8.7	16.1
Grey stentered 90%	6.0	6.4	5.5	15.0
Monofilament black	29.3	28.8	28.3	3.3
Yellow/White	14.9	15.4	14.3	6.7
Green Sample A1	10.0	9.5	11.8	10.4
Blue/White	7.1	7.6	12.1	14.3
Brown Sample A1	7.4	7.6	6.0	13.4
Yellow Sample B1	14.5	15.7	17.8	6.5
Red Sample B1	6.6	8.8	13.7	14.4
Green Sample B1	11.9	11.8	18.7	8.5
Tan Sample B1	17.3	18.9	18.6	5.7
Pink Sample B1	11.7	12.6	12.3	8.3
Blue Sample B1	9.9	10.5	14.0	10.3
Grey Sample B1	16.2	17.3	13.5	6.0
White Sample B1	13.5	16.2	13.0	7.2
Brown Sample B1	7.0	6.8	10.9	14.4
Blue Sample B2	20.9	25.1	14.0	4.3
Grey Sample B2	15.0	15.6	9.0	6.1
White Sample B2	16.4	18.9	18.2	5.6
Brown Sample B2	11.4	11.6	17.9	7.7
Black Shadecloth	12.5	12.5	12.3	7.2
White Shadecloth	16.3	16.5	14.8	5.1
Black 18x14 Shadecloth	54.5	54.9	54.2	1.8
Black 20x20 Shadecloth	43.2	42.8	42.9	2.3
Black 20x30 Shadecloth	32.0	31.7	31.0	3.0

[1,2]Tuvb and Tuva are the mean UVB and UVA percentage transmittance respectively
[3]Tvis is the visible transmittance
[4]PF is the protection factor

horticultural shadecloth. The spectrophotometer results are generally lower than those from the spectroradiometer as it is unable to collect radiation scattered at large angles and the beam diameter is of insufficient width to compensate for variations in the knit. For most of the shadecloths examined, the spectrophotometric measurements are not representative of the actual UVR transmission and will incorrectly suggest a higher degree of protection.

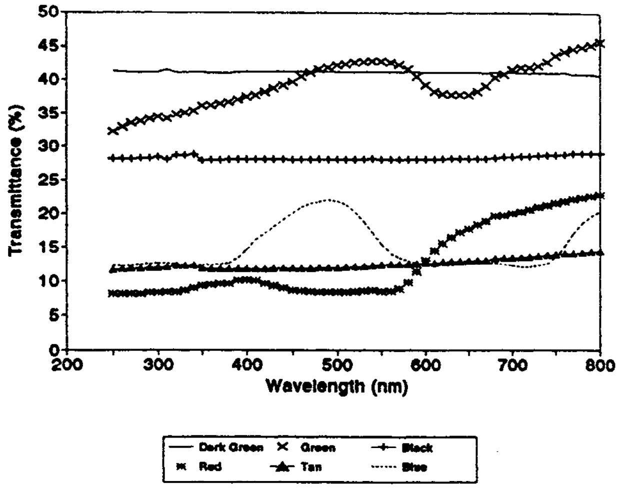

Figure 1. Spectral transmittances of some coloured horticultural shadecloths. Note the higher transmittances in the green, blue and red spectral regions.

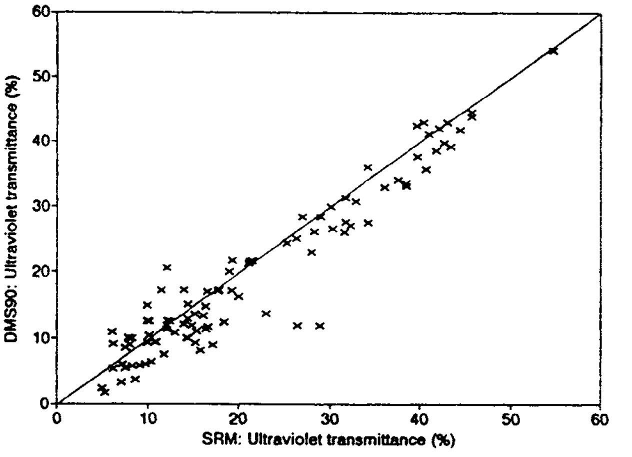

Figure 2. Comparison of the mean ultraviolet transmittance of horticultural shadecloth measured using the spectrophotometer and spectroradiometer. The good agreement is a result of the high transmittance of shadecloth.

Comparison of the spectrophotometer measurements of the mean percentage transmittance in the ultraviolet wavelength region with that in the visible is shown in Figure 3. The data show a reasonable correlation between the mean ultraviolet and mean visible percentage transmittance, with a gradient of 1.02 $\pm$ 0.01 and intercept of -1.45%. Spectroradiometric measurements of the mean UVR transmittance and the mean visible transmittance also showed good correlation. This suggests that the visible transmittance could provide a useful method for estimating the ultraviolet transmittance of horticultural cloth.

The outliers in Figure 3 are values where the mean transmittance in the visible spectral region is greater than the ultraviolet. As mentioned previously this is a result of some coloured shadecloths having non uniform transmission spectra across the visible wave band. This non uniformity results in an increase in the mean visible transmittance which is not indicative of the transmission in the ultraviolet.

B. Polycarbonates

The transmittance characteristics of various types of polycarbonate material are given in Table 3. Despite most of the polycarbonates being virtually transparent in the

Table 2

Mean spectral transmittance and protection factor of various parasol and canvas materials.

Material	Tuvb	Tuva	Tvis	PF
PARASOL				
Red	3.9	4.9	2.9	22.4
Yellow	13.1	15.5	3.4	5.8
Green	3.6	7.1	2.9	16.4
Blue	9.8	25.3	3.8	6.8
Rainbird 1	1.0	4.2	0.7	44.7
Rainbird 2	0.2	2.0	0.5	⟩50
CANVAS				
Natural	0.1	0.3	0.3	⟩50
Vanilla	0.1	0.0	0.1	⟩50
Black	0.1	0.0	0.1	⟩50
Colour	0.1	0.0	0.1	⟩50
Natural polyester/cotton	0.2	5.1	0.3	⟩50
Tan	0.1	0.2	0.1	⟩50
Green 100% acrylic	0.1	0.0	0.0	⟩50

Table 3

Mean spectral transmittance of various types of polycarbonate sheeting

Material	Tuvb	Tuva	Tvis	PF
Corrugated	0.0	4.0	89.9	⟩50
Greca	0.0	3.3	89.0	⟩50
0.8 mm Sample 1	0.0	3.5	81.9	⟩50
0.8 mm Sample 2	0.0	3.6	88.0	⟩50
0.8 mm Sample 3	0.0	4.2	85.0	⟩50
Suntuf 0.8 mm	0.0	2.5	82.1	⟩50
2 mm unstabilised	0.0	7.5	84.4	⟩50
Double Skin	0.0	4.3	77.8	⟩50
Twinwall	0.0	3.0	57.6	⟩50
0.8 mm tinted	0.0	0.9	34.9	⟩50
4.6 mm tinted	0.0	0.2	3.4	⟩50

visible, all samples had zero UVB transmittance and very low UVA transmittance. The low ultraviolet transmittance values indicate that polymeric materials provide substantial protection against solar UVR. Figure 4 shows the ultraviolet and visible transmission spectra of various clear and tinted polycarbonate sheeting. These materials strongly attenuate UVR and have a high and almost constant transmission throughout the visible wavelength region.

Personal Protection

Ambient solar UVR incident on a shelter consists of a non normal direct beam and a hemispherical diffuse field. The diffuse field, or sky component, is due to atmospheric scattering of UVR. Solar UVR levels inside the shadow of a shelter will be lower than outside as the covering material excludes most of the direct and diffuse radiation.

Shade structures can be beach umbrellas, or pergolas having shadecloth or polycarbonate sheeting as the shade rendering material. Most manufacturers advertise their product as blocking a certain percentage of ultraviolet radiation. What is usually not stated is that polycarbonate sheeting and shadecloth only prevent most of the direct UVR beam from reaching the region beneath the shading material. However, diffuse UVR is also present within the shelter as it enters through the side openings of the structure. The size of the structure and the area of the side openings influences the level of UVR in a shaded area. Scattered UVR within the shelter may lower the protection offered by the shading material in comparison with that calculated from the transmittance[11]. In addition, the received radiant exposure is also dependent on the position of the occupant within the shelter and the duration of exposure.

Trees and small, open sided structures, such as beach umbrellas, provide less protection against ambient solar UVR than a shelter of larger area. Small shelters only provide a barrier against direct sunlight. Diffuse UVR can reach the occupants if most of the sky is visible from within the shelter. Solar UVR scattered from the environment can still induce erythema, although erythema develops over a longer period than an exposure to full sun. Applying personal protection such as clothing, sunscreens, and sunglasses is recommended when in a small shaded area as these measures reduce exposure to scattered UVR.

The position of an individual within a shaded area is more significant, in terms of radiant exposure, for large shelters. The amount of scattered radiation under a small shelter, a beach umbrella for instance, is approximately uniform, therefore the UV exposure received at either a peripheral or central position may not be significantly different and could be quite high. With large structures, for example a gazebo, a person situated near the boundary receives a greater UV dose, as they are subjected to a substantial field of sky radiation, than if centrally positioned. As a person moves towards the centre of a large structure the amount of scattered and diffuse radiation received from the edges of the structure will decrease. A strong influence on radiant exposure results from a northern boundary position where the dose received can be due to direct and scattered UVR.
The effective protection provided by natural and constructed shade against direct solar UVR is related to shade density, which is dependent on the size of the openings in the material. Openings in the plant canopy and horticultural shadecloth transmit 100% of solar ultraviolet and visible radiation. Less shade is cast from screens comprising mainly of open spaces. Lightly shaded areas provide less protection against direct solar UVR. In contrast, denser shadows represent greater protection against ultraviolet radiation.

The effective protection of polycarbonate sheeting against

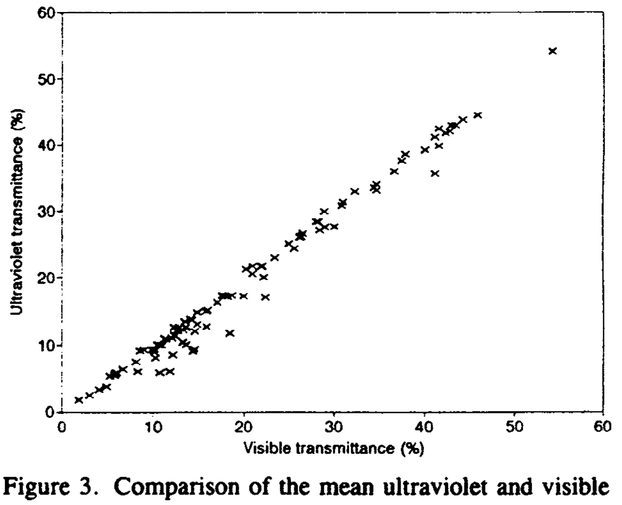

Figure 3. Comparison of the mean ultraviolet and visible transmittance of horticultural shadecloth. A 1:1 agreement is expected as shadecloth acts as a physical barrier to ultraviolet and visible radiation.

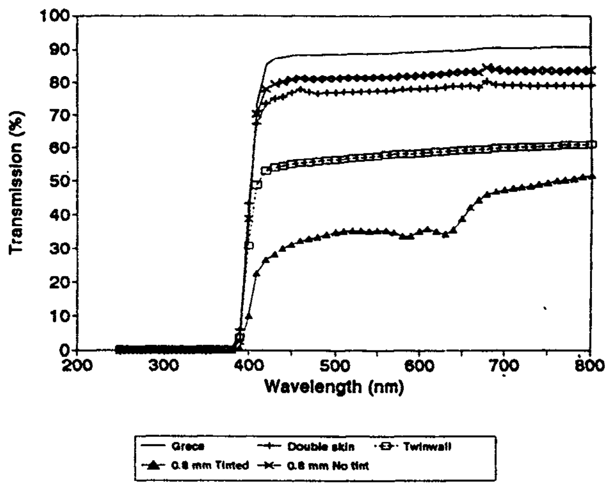

Figure 4. Transmittance spectra of various types of polycarbonate sheeting. Note the low UVR transmittances and the near constant transmittances in the visible spectral region.

solar UVR is not related to shade density. Polycarbonate sheeting, due to its transparent nature, casts a faint shadow unless heavily tinted. However, the ultraviolet protection is not affected as the polymers within the material absorb UVR.

Conclusions

Of the shade materials evaluated in this work canvas materials provided the greatest protection against solar ultraviolet radiation, followed by polycarbonate sheeting and horticultural shadecloth. Horticultural cloths transmit between 10% and 50% of the incident radiation.

The shadecloths had a uniform transmittance across the UVB and UVA spectral regions, and the percentage of direct radiation reaching an area beyond the fabric is dependent on the closeness of the weave. Close correlation exists between the mean UVR and mean visible spectral transmittance suggesting that the visible transmission is a reasonable estimate for the ultraviolet transmittance.

While staying in shade out of direct sunlight is advisable, people may still be exposed to scattered UVR from the sky. The UVR dose received is dependent on the amount of sky visible from within the sheltered area and the duration of exposure. Consequently, the more sky visible to the subject, the greater their exposure to scattered UVR. The use of additional protection such as clothing, sunscreen and sunglasses is recommended in the shaded area to minimise exposure to scattered UVR.

References

1. Giles, G.G., Marks, R. and Foley, P., "Incidence of non-melanocytic skin cancer treated in Australia", British Medical Journal (1988), 296, 13-17.

2. Holman, C.D., Mulroney, C.D. and Armstrong, B.K., "Epidemiology of preinvasive and invasive malignant melanoma in Western Australia", International Journal of Cancer (1980), 41, 757-763.

3. Holman, C.D.J., Armstrong, B.K. and Heenan, P.J., "Relationship of cutaneous malignant melanoma to individual sun exposure habits", Journal of the National Cancer Institute (1986), 76, 403-414.

4. Standards Australia, "Synthetic shadecloth". AS 4174 (1994).

5. Berre, L. and Lala, D., "Investigation on photochemical dosimeters for ultraviolet radiation", Solar Energy (1989), 42, 405-416.

6. Davis, A., Developments in Polymer Degradation. Chapter 9. Applied Science Publishers, 1977.

7. Gies, H.P., Roy, C.R. and Elliott, G., "Ultraviolet radiation protection factors for personal protection in both occupational and recreational situations", Radiation Protection in Australia (1992), 10, 59-66

8. CIE Research Note, "A reference action spectrum for ultraviolet induced erythema in human skin", CIE J. (1987), 6, 17.

9. Kelfkens, G., De Gruijl, F.R. and Van Der Leun, J.C., "Ozone depletion and increase in annual carcinogenic ultraviolet dose", Photochemistry and Photobiology (1990), 52, 819-823.

10. Welsh, C. and Diffey, B., "The protection against solar actinic radiation afforded by common clothing fabrics", Clinical and Experimental Dermatology (1981), 6, 577-582.

11. Wong, C.F., "Scattered ultraviolet radiation underneath a shade cloth", Photodermatology, Photoimmunology and Photomedicine (1994), 10, 221-224.