ERYTHEMAL IRRADIANCES

OF FILTERED ULTRAVIOLET RADIATION

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Short title: Erythemal irradiances of filtered UV

Abstract

A spectrum evaluator (3 cm x 3 cm) employing four passive dosimeters has been used to evaluate the time averaged spectrum to allow calculation of the erythemal exposures resulting from the predominantly UVA component of filtered solar ultraviolet radiation. An exposure interval of approximately 20 minutes to autumn and spring sunshine was required for the spectrum evaluator to allow evaluation of the filtered source spectrum. For a clear spring day an erythemal exposure of 0.85 MED to a horizontal plane and 0.38 to a vertical plane over a six hour period was measured within a glass enclosure. For a partially cloudy day six weeks later, these were 0.89 MED and 0.44 MED for the horizontal and the vertical planes respectively. The exposure is predominantly due to the UVA component of the solar radiation. The ratios of the filtered to the unfiltered erythemal exposures within and outside the enclosure respectively ranged from 0.08 to 0.18 throughout the two days.

1. INTRODUCTION

Solar ultraviolet (UV) radiation (280-400 nm) is absorbed selectively (predominantly in the UVB waveband) in materials such as polycarbonates and glass. The spectrum of filtered UV may be substantially different from that of the solar UV spectrum reaching the earth directly from the sun. Recent publications (Anders *et al*., 1995, Lavker *et al*., 1995a, 1995b) have reported the damaging effects of UVA radiation on humans and the induction of tumours in hairless mice by UVA radiation (Kelfkens *et al*., 1992). Much of the skin damage induced by UVB (280-320 nm) wavelengths may also be induced by UVA (Urbach, 1993). Research on the effects of solar UV radiation on the human skin requires the measurement of erythemal irradiance (Diffey, 1986). The magnitude of erythemal irradiance (UV_{ery}), due to filtered UV depends on the source spectral composition $S(\lambda)$ as follows:

$$UV_{ery} = \int_{uv} S(\lambda)A(\lambda)d\lambda \quad \mu W\ cm^{-2} \qquad (1)$$

where $A(\lambda)$ is the action spectrum for erythema in humans (CIE, 1987) and the integration interval is over the solar UV wavelengths. A feature of the human erythemal action spectrum (Figure 1) is a low (relative effectiveness less than 0.01), but significant effectiveness in the UVA (320-400 nm) waveband. The contribution of the UVA wavelengths to erythema becomes more significant compared to the contribution from UVB wavelengths if the UVB wavelengths are removed by a barrier, for example, glass (Gies *et al*., 1992).

Conventional methods utilising polysulphone (Diffey 1989) as dosimeters for the determination of erythemal irradiance for filtered UV require calibration at the site of measurement. This is not only difficult but impractical. Furthermore, the spectral response to UVA wavelengths of polysulphone (CIE, 1992) is very low (Figure 1). For wavelengths longer than 320 nm, the response of polysulphone is less than 1% of the maximum value at 295 nm. As a result, individual polysulphone dosimeters cannot be employed to measure the erythemal exposure due to UVA radiation.

A portable spectrum evaluator, utilising dosimeter materials polysulphone, nalidixic acid (NDA), 8-methoxypsoralen (8MOP) and phenothiazine, has been employed to evaluate the erythemal irradiances due to UVA radiation from a lamp (Wong and Parisi, 1996). The system of four dosimeter materials is small and compact (3 cm x 3 cm) with a different one of the four dosimeter materials placed over each of the four holes of 0.6 cm diameter. The spectrum evaluator has been employed to evaluate the solar UV spectrum at multiple sites over an object of study (Parisi and Wong, 1996, Parisi *et al*., 1996). This paper presents results employing the spectrum evaluator to measure the erythemal irradiances due to filtered solar UV radiation.

2. MATERIALS AND METHODS

Filtered UV

A series of Schott glass long-pass filters, WG305, WG320, WG335, WG345 and WG360, each of 3 mm thickness (Schott, Mainz, Germany) with incrementally increasing cut-off wavelengths were employed to produce filtered UV. A piece of thick glass (6.3 mm thick), thin glass (1.25 mm thick) and perspex (4.2 mm thick) were also employed as filters. The solar UV spectral irradiance was measured at Brisbane,

Australia on 3 April, 1996 on a totally cloud free autumn day between 10:42 and 12:02 Eastern Standard Time (EST) for unfiltered sunshine and sunshine filtered with each of the Schott glass filters. On 10 September, 1996, the spectral irradiance of unfiltered sunshine and sunshine filtered with the thick glass was measured under a clear sky at approximately 11:30 EST. The UV spectral irradiance filtered by the thin glass and the perspex was measured employing a 250 W quartz tungsten halogen (QTH) lamp (model SYL-235, Sylvania, Japan) as the source at a distance of 10 cm.

The spectrum was measured with UV spectroradiometers based on a double holographic grating monochromator (model DH10UV, Jobin Yvon Co., France). The input optics to the monochromator were provided by an integrating sphere. For the data collected in April, the spectroradiometer employed had a 10 cm integrating sphere (model IS-040, Labsphere Inc., North Sutton, USA). For the remainder of the measurements, the spectroradiometer utilised a 15 cm diameter integrating sphere (model OL IS-640, Optronics Laboratories, Orlando, USA). The spectroradiometers were calibrated at the field site against a 250 W QTH lamp (model A1/235, Thorn Co., UK) at a current of 9.5 A. The calibration of the lamp was traceable to the Australian standard lamp at the National Measurement Laboratory, CSIRO, Lindfield. The filtered spectrum was measured by placing the filter directly over the input aperture of the integrating sphere of the spectroradiometer.

Spectrum evaluator

The materials polysulphone, NDA, 8MOP and phenothiazine employed in the spectrum evaluator degrade on exposure to UV radiation. The degradation was quantified by measuring the change in optical absorbance (ΔA) of each material with a dual beam spectrophotometer (Shimadzu Co., Kyoto, Japan). The optical absorbance was measured before and after exposure at the wavelength for which the largest change occurs, namely, 330 nm for polysulphone and NDA, 305 nm for 8MOP and 280 nm for phenothiazine. For each material the ΔA as a result of exposure to a UV source spectrum for a period, T is:

$$\Delta A = T\int_{uv} \overline{S(\lambda)} R(\lambda) d\lambda \qquad (2)$$

where $R(\lambda)$ is the spectral response of each material and $\overline{S(\lambda)}$ is the time averaged UV spectrum defined as:

$$\overline{S(\lambda)} = \frac{1}{T}\int_0^T S(\lambda, t) dt \qquad (3)$$

For a UV exposure, measurement of ΔA and knowledge of $R(\lambda)$ for each material allows the time averaged source spectrum to be evaluated as described in Parisi *et al*. (1997). The technique employed was to approximate the spectrum with a polynomial function and determine the parameters of the function by a non-linear iterative technique. The function is:

$$\overline{S(\lambda)} = (\lambda - \lambda_0)\left(\sum_{i=1}^{4} a_i \lambda^{i-1}\right) \qquad (4)$$

where λ_0 is the wavelength at which the spectral irradiance is approximately zero due to lower wavelengths being filtered and a_i are the coefficients to be determined.

The spectrum evaluator was employed for the assessment of erythemal irradiance due to filtered UV from the 250 W QTH lamp at a distance of 10 cm powered by a current

regulated power supply at 9.5 A. The perspex, thick and thin glass were employed as filters. The exposure times for the spectrum evaluator employed for each filter are provided in Table 1. These were chosen in order to produce a measurable change in absorbance of the dosimeter material as measured with the spectrophotometer. For comparison, the filtered UV spectrum was also measured with the calibrated spectroradiometer. The erythemal irradiances through each filter material were found by convolving and summing the measured spectral irradiance with the erythemal action spectrum (Figure 1) in 1 nm steps over the waveband for which the transmission through the filter was non zero.

On a totally cloud free autumn day (3 April, 1996) in Brisbane, a spectrum evaluator was exposed under each of the Schott glass filters in turn to evaluate the filtered time averaged UV spectrum. The start time and exposure period utilised for each filter is shown in the third and fourth columns of Table 2. At the same time, the input aperture of the calibrated spectroradiometer was covered with a Schott filter of the same type and the filtered spectral irradiance measured. The evaluation of the solar spectrum through the Schott glass filters was repeated for three twenty minute periods starting at 10.02, 10.50 and 11.31 EST on a cloud free day on 22 August and the respective erythemal exposures compared to those obtained by measuring the filtered solar spectrum with the spectroradiometer.

The individual dosimeter materials polysulphone, NDA, 8MOP and phenothiazine were calibrated for erythemal exposure against the calibrated spectroradiometer for solar radiation in late autumn employing the technique described elsewhere (Wong *et al*., 1992). The erythemal exposures measured with the individual dosimeters were compared to those obtained employing the erythema action spectrum with the spectra evaluated with the spectrum evaluator and those measured with the spectroradiometer.

Erythemal UVA

Five of the spectrum evaluators were exposed to solar UV at 11:23 EST on 3 September in Toowoomba, Australia under a glass enclosure comprising a glass top and four glass sides (465 mm long, 235 mm wide and 230 mm high). The glass was approximately 3 mm thick on the base and two sides and 4 mm thick on the remaining two sides. The exposure was designed to simulate and measure the erythemal exposure that would be received behind a glass barrier such as in a glass house or behind window glass, for example, a car or office window. One of the spectrum evaluators was on a horizontal plane with the other four on a vertical plane facing north, east, south and west respectively. The spectrum evaluators were exposed to the filtered sunlight for a period of twenty minutes. For this day, the Meteorology Bureau observer in Toowoomba provided the cloud cover as 6 eighths at 9:00 EST and 3 eighths at 15:00 EST. The exposure of the spectrum evaluators under the glass barrier was repeated on 4 September at 9:00, 11:50 and 14:40 EST for a period of twenty minutes (free of cloud) in each case and again on 18 October at 9:00, 11:50 and 14:40 EST for a period of twenty minutes. The cloud cover on 18 October was 1 eighth at 9:00 EST and 6 eighths at 15:00 EST. For the 4 September and 18 October, the ambient erythemal exposure on a horizontal plane outside of the glass enclosure was measured with a Robertson-Berger (RB) meter (model 3D, Solar Light Co., Philadelphia, USA). The RB meter was calibrated against the spectroradiometer.

3. RESULTS

Filtered UV

A typical solar UV spectrum obtained on a clear sky day at approximately 11:30 EST on 10 September at Brisbane is provided in Figure 2 along with the UV spectrum filtered by the thick glass filter (as described previously) that was measured under similar conditions. The UVB component (wavelengths shorter than 320 nm) is completely filtered by the glass with a large component of the UVA remaining. The erythemal irradiance as a result of UVA for the filtered radiation is 0.6 $\mu W\ cm^{-2}$ or 0.11 MED hr^{-1} as calculated employing Equation (1). 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 24 hrs following exposure in people of skin type 1. This is in comparison to 1.6 $\mu W\ cm^{-2}$ or 0.29 MED hr^{-1} for the UVA component of the unfiltered radiation. In this situation where the UVB component has been filtered, the photobiological effect of UVA radiation on humans becomes an important issue and measurement of the erythemal UVA is necessary for assessing erythemal UV radiation.

Figure 3 shows a typical unfiltered solar spectrum and filtered with Schott WG305, WG320, WG335, WG345 and WG360 filters recorded on a day free of cloud on 3 April in Brisbane between 10:42 and 12:02 EST. The filters produce incremental cut-off wavelengths at approximately 303, 307, 320, 339 and 345 nm respectively. The unfiltered QTH lamp spectrum and the spectrum filtered with perspex and thin glass are shown in Figure 4. The perspex and the thin glass provide cut-off wavelengths of approximately 338 and 320 nm respectively.

Spectrum evaluator

The erythemal irradiances for the filtered UV from the QTH lamp and the spectra evaluated utilising the spectrum evaluator and those measured employing the spectroradiometer are provided in the final two columns of Table 1. The cut-off wavelengths employed for each filter in the function to evaluate the spectrum are provided in the third column of this Table. The measured and evaluated spectra for the QTH lamp filtered by the thick and thin glass and the perspex respectively are shown in Figure 5. For the solar spectrum, the evaluated spectra obtained on 3 April compared to the spectra measured with the spectroradiometer are provided in Figure 6. The evaluated spectra are smoothed versions of the measured spectra. The results of the measured and evaluated irradiances for the filtered solar UV are provided in Table 2. The differences between the measured and evaluated erythemal irradiances are less than 20%. The filters utilised in this experiment have a spectral transmittance of long wavelength UV down to a cutoff wavelength. There is negligible transmittance for wavelengths shorter than the cutoff wavelength. It is interesting to note that as the cutoff wavelength of the filter increases from 303 nm to 307 nm, the erythemal irradiance decreases by about 50% (Table 2). There is another approximately 50% reduction in the erythemal irradiance as the cutoff wavelength further increases from 307 nm to 320 nm. On 22nd August 1996 in Brisbane, the erythemal irradiance filtered by cutoff wavelengths longer than 320 nm did not vary more than 10%. This suggests that the presence of UVA erythemal irradiance in solar radiation does not vary significantly with the increase of the solar elevation angle.

The spectrum evaluator provides the time averaged spectrum over the period of exposure. The exposure period was selected as a compromise value that was long enough to produce a measurable effect on the dosimeter material and sufficiently short to minimise any changes in the solar spectrum. The change in erythemal irradiances over the exposure period was calculated employing the spectral irradiance measured with the spectroradiometer. The variation in filtered erythemal irradiance over the exposure period of about 20 min was found to be less than 14%. The spectrum evaluator takes this into account as it allows evaluation of the time averaged spectrum. This is applied in determining the filtered erythemal exposures over the interval.

The results of employing each of the individual dosimeters calibrated for erythemal exposure to measure the filtered erythemal UV are provided in the final four columns of Table 3 for the 3 April and 22 August exposures. These are compared to those obtained by employing Equation (1) and the spectra evaluated and measured with the spectrum evaluator and spectroradiometer respectively (previous two columns). For the WG335, WG345 and WG360 filters, the change in absorbance for polysulphone as a result of exposure was less than 3%. This is due to all of the UVB wavelengths being filtered and the dosimeter is not sensitive to the long wavelengths in the UVA waveband. For the other three dosimeter materials for these filters, the differences between the erythemal exposures measured with the individual dosimeter and those obtained employing the calibrated spectroradiometer are not uniform and they ranged up to approximately 400%. These results are due to the calibration problem as the spectral response function of these dosimeters does not match the human action spectrum for erythema. Consequently, the calibration must be made for each source spectrum (Wong *et al.*, 1995). As a result, the individual dosimeters could not have been employed to provide the erythemal exposures for the filtered UV.

Erythemal UVA

The erythemal exposures in units of MED for the five orientations under the glass enclosure at the four different times are provided in Table 4. The change in absorbance for the polysulphone was approximately zero in each case. For 4 September, the erythemal exposures of 0.041, 0.055 and 0.037 MED, measured with the spectrum evaluator, on a horizontal plane for 09:00 to 09:20, 11:50 to 12:10 and 14:40 to 15:00 EST respectively require exposure periods of 8.1, 6.0 and 9.0 hours respectively to produce a 1 MED exposure. Employing the erythemal exposures measured for the periods starting at 09:00, 11:50 and 14:40 EST and interpolating over the 6 hr period provides an erythemal exposure for the six hour period of 17 mJ cm^{-2} or 0.85 MED. Similarly for the 18 October, the six hour exposure is 0.89 MED.

The ambient exposures for the 20 min periods measured with the RB meter outside of the glass enclosure were 0.24, 0.49 and 0.21 MED respectively for the morning, noon and afternoon periods on 3 September. Dividing the exposures within the glass enclosure on a horizontal plane by those measured outside the enclosure produces ratios of 0.17, 0.11 and 0.18 for the respective sessions. On the 18 October, the ambient exposures outside the glass enclosure for the same morning, noon and afternoon periods were 0.43, 0.70 and 0.25 MED respectively. On this day, the afternoon exposure was affected by the 6 eighths of cloud cover at the time. The ratios of the erythemal UVA exposures determined inside and outside the glass enclosure on a horizontal plane were 0.11, 0.08 and 0.15. These results show that the ratio of the exposures within and

outside the glass enclosure changes throughout the day due to the UV transmission of the glass changing as the zenith angle of the sun varies. The changing angle of the sun also affects the reflected UV within the enclosure. In addition, the above results show that the ratio also changes with time of year. The smaller value of the ratios for each respective period on 18 October shows the changing ratio of erythemal UVA compared to the erythemal UVB as the solar elevation angle increases.

Taking the averages of the exposures on a vertical plane for the north, east, south and west orientations provides erythemal irradiances of 0.024 MED for the 20 min interval on 3 September and 0.023, 0.020 and 0.022 MED for the morning, noon and afternoon periods respectively for the 4 September. The noon exposure on the second day for the vertical plane is lower compared to the morning and afternoon exposures due to the higher altitude angle of the Sun at that time. The noon erythemal exposure on 3 September is higher than on the following day. This may be due to the higher component of diffuse UV compared to the direct component resulting from the cloud cover on 3 September. Interpolating provides an integrated erythemal UVA exposure for the six hours to a vertical plane of 7.7 mJ cm^{-2} or 0.38 MED. For the 18 October, erythemal UVA exposures of 0.028, 0.025 and 0.020 MED were obtained to the vertical plane for the morning, noon and afternoon periods respectively. The afternoon exposure is low due to the heavier cloud cover at the time. Interpolating over the six hour period provides a cumulative exposure of 0.44 MED.

4. CONCLUSION

This paper has presented results of evaluating erythemal irradiances resulting from filtered UV radiation employing a method based on passive dosimeters. Specifically, the method has application in evaluating the erythemal exposure as a result of solar UVA radiation due to UV radiation filtered by glass. The personal exposure to solar erythema UVA cannot be measured accurately by any other form of currently available dosimeter material. For the solar exposures in this paper during autumn and spring, the spectrum evaluator required an exposure of about 20 min to allow evaluation of the spectrum. The erythemal exposures evaluated with the spectrum evaluator employ the time averaged source spectrum. Consequently, this incorporates any changes in the source spectrum resulting from either variations in the atmosphere or surroundings for the case of the solar spectrum or drifts in the lamp and power supply output for the case of the lamp spectrum. On the other hand, the use of a spectroradiometer to measure the spectrum at one point of time to determine the total erythemal exposure over an exposure period can introduce an error if the source spectrum changes significantly. This may be the case if the amount of cloud cover varies.

The ratios of the erythemal exposures on a horizontal plane within and outside the glass enclosure varied throughout the day and the time of year. The ratios were 0.17, 0.11 and 0.18 for the morning, noon and afternoon periods respectively and 0.11, 0.08 and 0.15 for the same times of the day six weeks later. Consequently, a measurement of the ambient erythemal exposure on a horizontal plane cannot provide the erythemal exposure received behind glass.

Over a six hour period on a clear spring day, an erythemal exposure of 0.85 MED to a horizontal plane and 0.38 MED averaged over the north, east, south and west orientations in the vertical plane was obtained within a glass enclosure with the

spectrum evaluators described in this paper. Similarly, for a partially cloudy spring day six weeks later, erythemal UVA exposures of 0.89 MED and 0.44 MED were measured under the glass enclosure to the horizontal plane and the vertical plane respectively. Results in the literature (Lavker *et al*., 1995a) have shown the effects of UVA radiation are cumulative and repetitive exposures to doses of less than 1 MED produce significant photobiological damage in human skin. The technique described in this paper provides a method for evaluating the erythemal exposures due to filtered UV radiation for any orientation over the object of study.

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Table 1 - Measured and evaluated erythemal irradiances for filtered QTH lamp UV.

Filter	Exposure (Minutes)	Cut-off (nm)	Erythemal Irradiance ($\mu W\ cm^{-2}$)	
			Measured	Evaluated
Thin glass	60	320	0.28	0.26±0.05
Thick glass	60	330	0.18	0.18±0.04
Perspex	60	338	0.16	0.14±0.03

Table 2 - Measured and evaluated erythemal irradiance for filtered solar UV.

Date	Filter	Cut-off (nm)	Start Time (EST)	Exposure (Minutes)	Erythemal Irradiance ($\mu W\ cm^{-2}$)	
					Measured	Evaluated
3-4-96	WG305	303	9.55	19	6.1	6.1±1.2
	WG305	303	11.58	10	7.2	7.8±1.6
	WG335	320	10.36	17	1.4	1.2±0.2
	WG345	339	11.12	17	0.69	0.64±0.13
	WG360	345	11.12	17	0.55	0.56±0.11
22-8-96	WG305	303	10.02	20	3.3	3.6±0.7
	WG320	307	10.02	20	1.6	1.9±0.4
	WG335	320	10.02	20	0.68	0.62±0.12
	WG345	339	10.02	20	0.36	0.42±0.08
	WG360	345	10.02	20	0.30	0.29±0.06
	WG305	303	10.50	20	4.3	3.6±0.7
	WG320	307	10.50	20	2.4	2.0±0.4
	WG345	339	10.50	20	0.42	0.41±0.08
	WG360	345	10.50	20	0.34	0.32±0.06
	WG305	303	11.31	20	4.4	3.7±0.7
	WG320	307	11.31	20	2.6	2.2±0.4
	WG335	320	11.31	20	0.90	0.75±0.15
	WG345	339	11.31	20	0.41	0.47±0.09
	WG360	345	11.31	20	0.33	0.39±0.08

Table 3 - Comparison of the erythemal exposures measured with the individual dosimeters with those from the spectroradiometer and spectrum evaluator.

Date	Filter	Start Time (EST)	Erythemal exposure (mJ cm^{-2})					
			Spectro-radiometer	Spectrum Evaluator	PS	NDA	8MOP	Phen
3-4-96	WG305	9.55	6.9	6.9±1.4	6.4	10.0	7.0	9.0
	WG305	11.58	4.3	4.7±0.9	3.2	5.8	3.8	1.9
	WG335	10.36	1.4	1.1±0.2	0.0	3.8	4.2	2.8
	WG345	11.12	0.70	0.65±0.13	0.0	0.5	1.7	1.7
	WG360	11.12	0.56	0.57±0.11	0.0	0.1	1.5	1.6
22-8-96	WG305	10.02	4.0	4.3±0.9	2.5	3.9	3.5	1.7
	WG320	10.02	2.0	2.3±0.5	1.2	3.1	3.9	2.4
	WG335	10.02	0.82	0.74±0.15	0.1	1.7	2.0	1.7
	WG345	10.02	0.43	0.50±0.10	0.0	0.3	0.3	1.8
	WG360	10.02	0.36	0.35±0.07	0.1	0.3	0.3	2.4
	WG305	10.50	5.2	4.3±0.9	2.4	4.4	4.4	2.0
	WG320	10.50	2.9	2.4±0.5	1.2	4.1	4.7	1.8
	WG345	10.50	0.5	0.49±0.10	0.0	0.3	1.7	2.2
	WG360	10.50	0.41	0.38±0.08	0.0	0.0	1.3	2.5
	WG305	11.31	5.9	4.9±1.0	2.8	4.8	5.7	2.1
	WG320	11.31	3.4	2.9±0.6	1.3	4.8	4.1	13.5
	WG335	11.31	1.2	1.0±0.2	0.0	2.0	2.9	3.9
	WG345	11.31	0.5	0.6±0.1	0.0	0.3	1.5	1.7
	WG360	11.31	0.4	0.5±0.1	0.0	0.1	1.3	2.0

Table 4 - Erythemal exposures in the glass enclosure for five different orientations on three different days.

		Erythemal exposure (MED)		
Date	Orientation	Morning	Noon	Afternoon
3 Sept 1996	Horizontal		0.052	
	Vertical - north		0.047	
	Vertical - east		0.014	
	Vertical - south		0.017	
	Vertical - west		0.019	
4 Sept 1996	Horizontal	0.041	0.055	0.037
	Vertical - north	0.032	0.034	0.028
	Vertical - east	0.032	0.013	0.011
	Vertical - south	0.015	0.018	0.015
	Vertical - west	0.014	0.015	0.035
18 Oct 1996	Horizontal	0.048	0.056	0.037
	Vertical - north	0.031	0.036	0.025
	Vertical - east	0.041	0.014	0.011
	Vertical - south	0.021	0.026	0.020
	Vertical - west	0.018	0.023	0.026

Figure 1 - (1) The human erythemal action spectrum (CIE, 1987) and (2) the relative response of polysulphone film (CIE, 1992).

Figure 2 - A typical solar UV spectrum (1) unfiltered and (2) filtered by glass, obtained on a clear sky day.

Figure 3 - The solar UV spectrum on 3 April that was (1) unfiltered and filtered with (2) WG305, (3) WG320, (4) WG335, (5) WG345 and (6) WG360 Schott glass filters.

Figure 4 - The (1) unfiltered QTH lamp UV spectrum and the QTH spectrum filtered with (2) thin glass and (3) perspex.

Figure 5 - The evaluated QTH lamp UV spectra (–––) and the spectra measured with the spectroradiometer (◆◆◆◆) for thick and thin glass and perspex.

Figure 6 - The evaluated solar UV spectra (–––) and the spectra measured with the spectroradiometer (◆◆◆◆) on 3 April for the various filters.

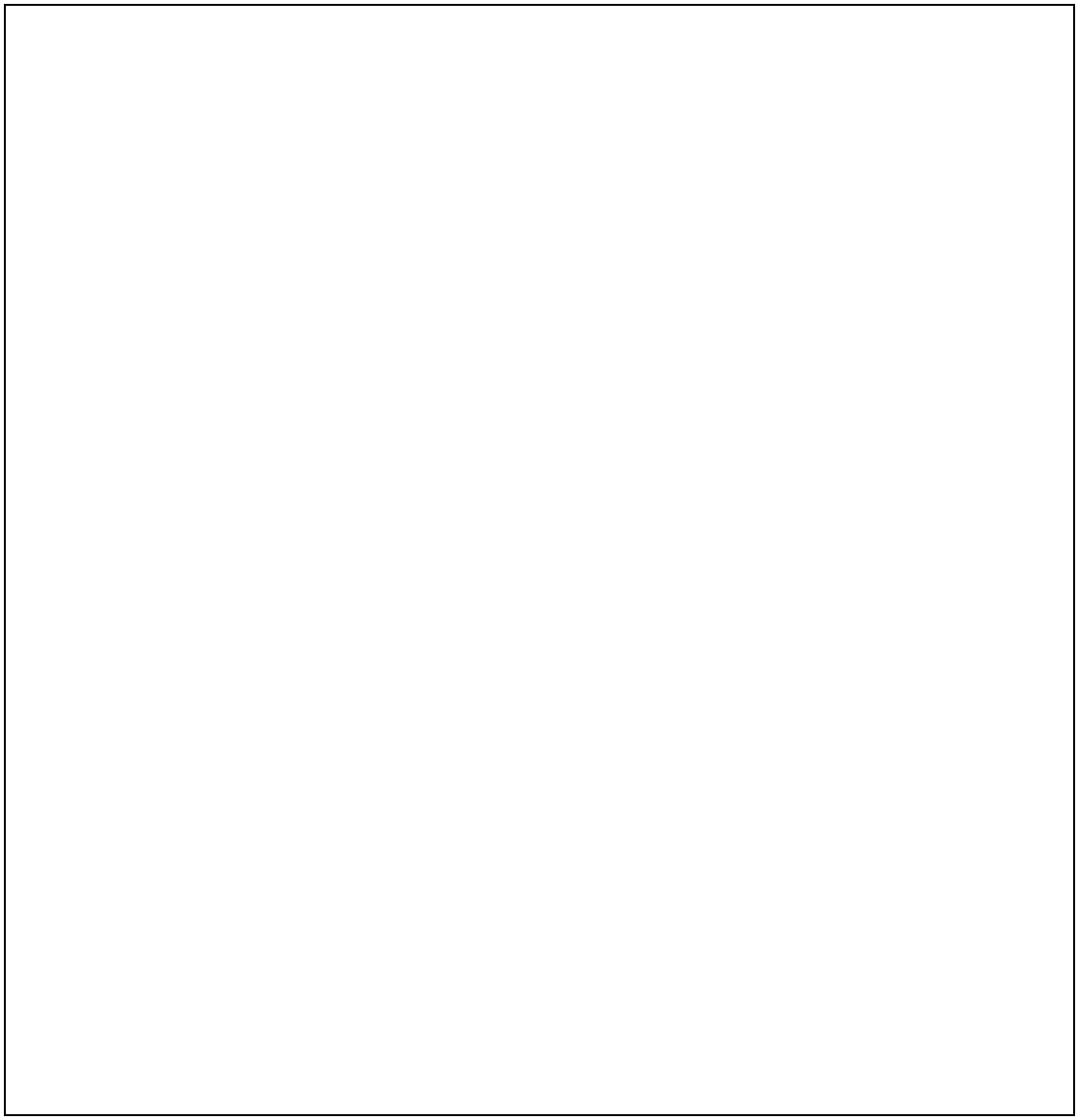

Figure 1.

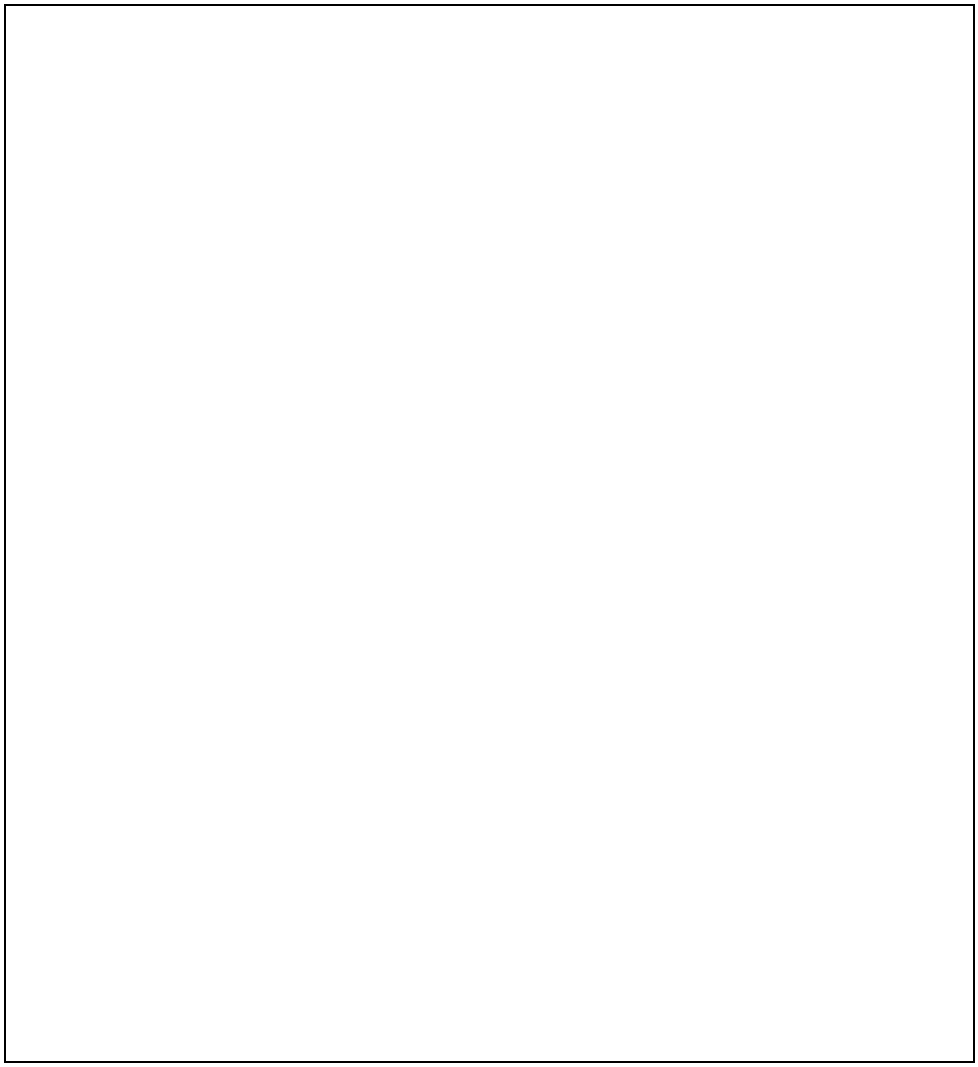

Figure 2.

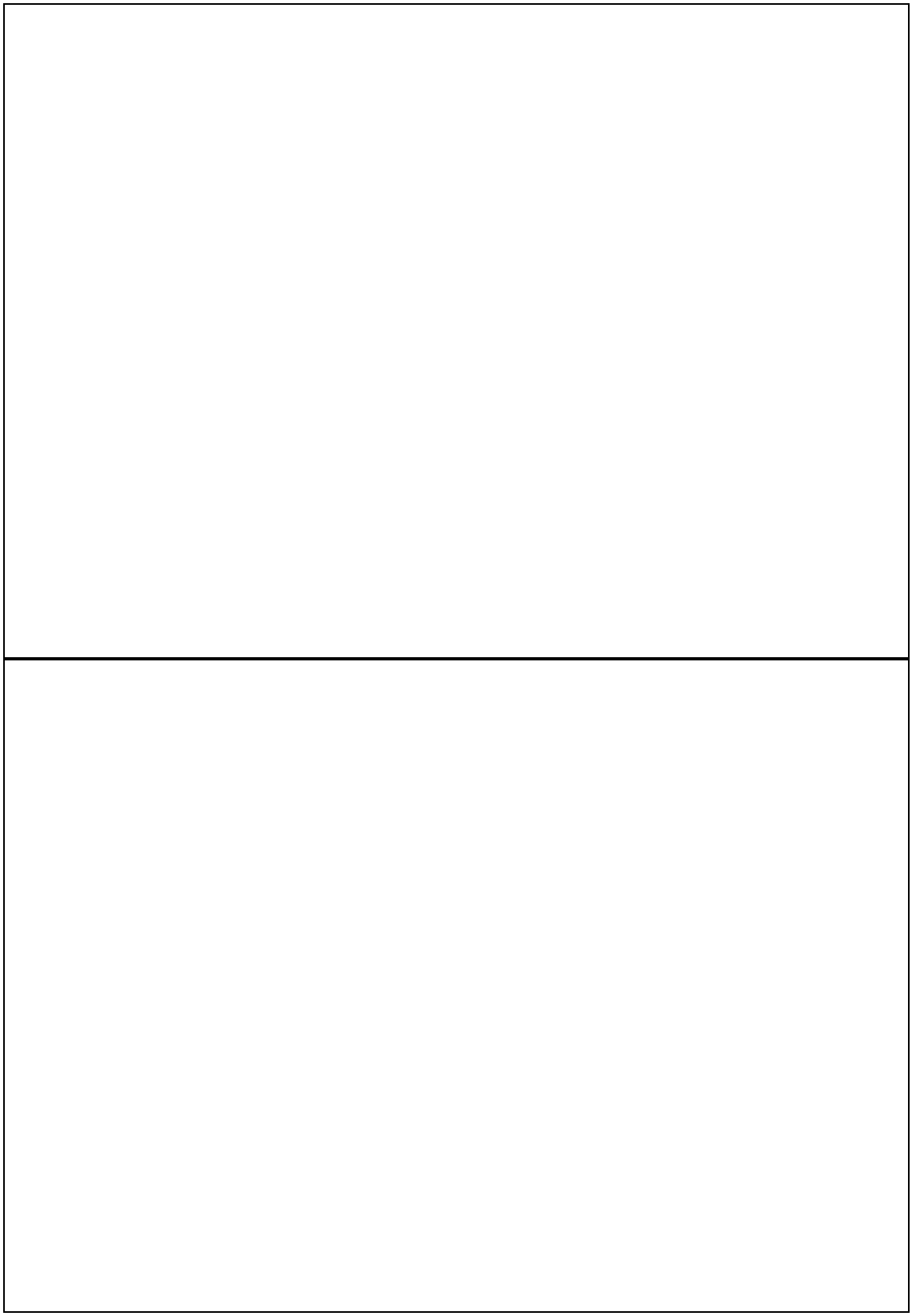

Figure 3.

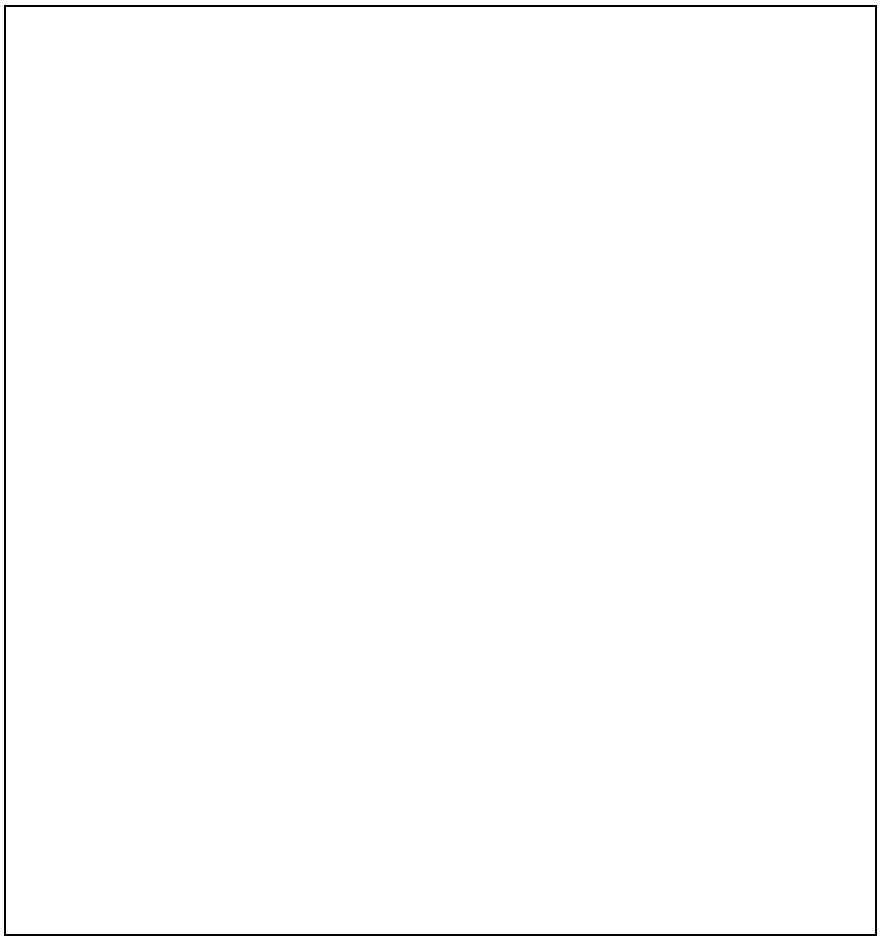

Figure 4.

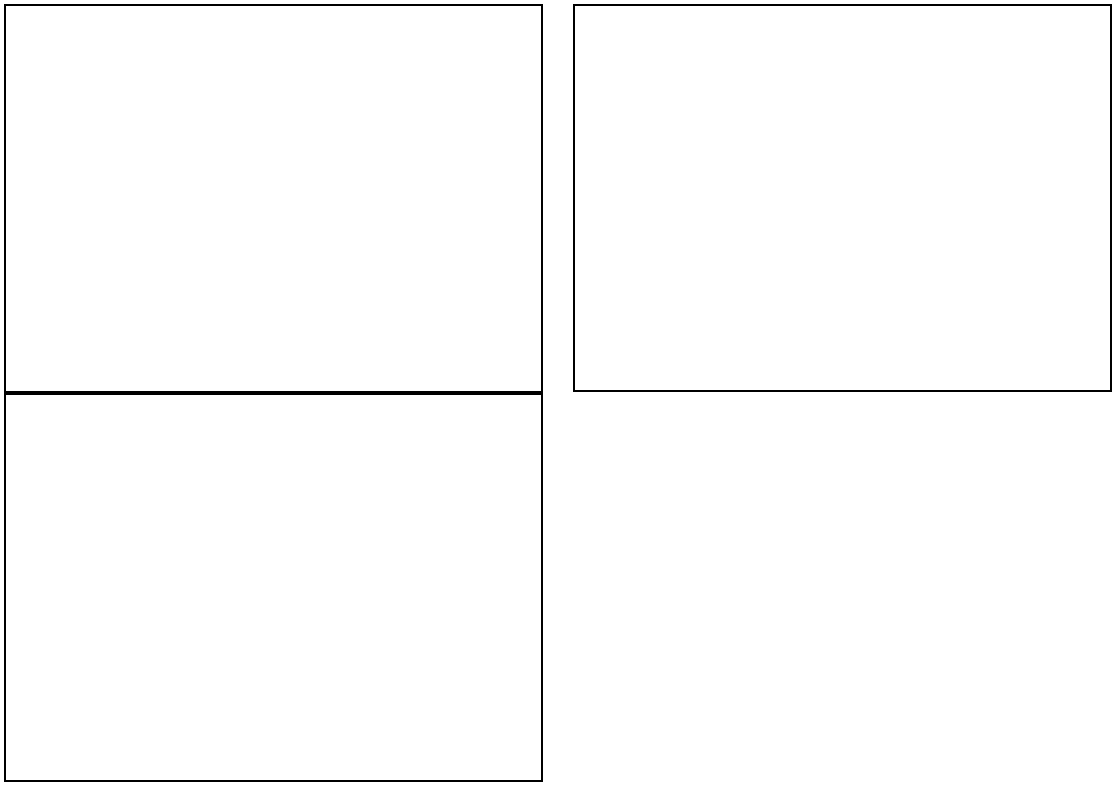

Figure 5.

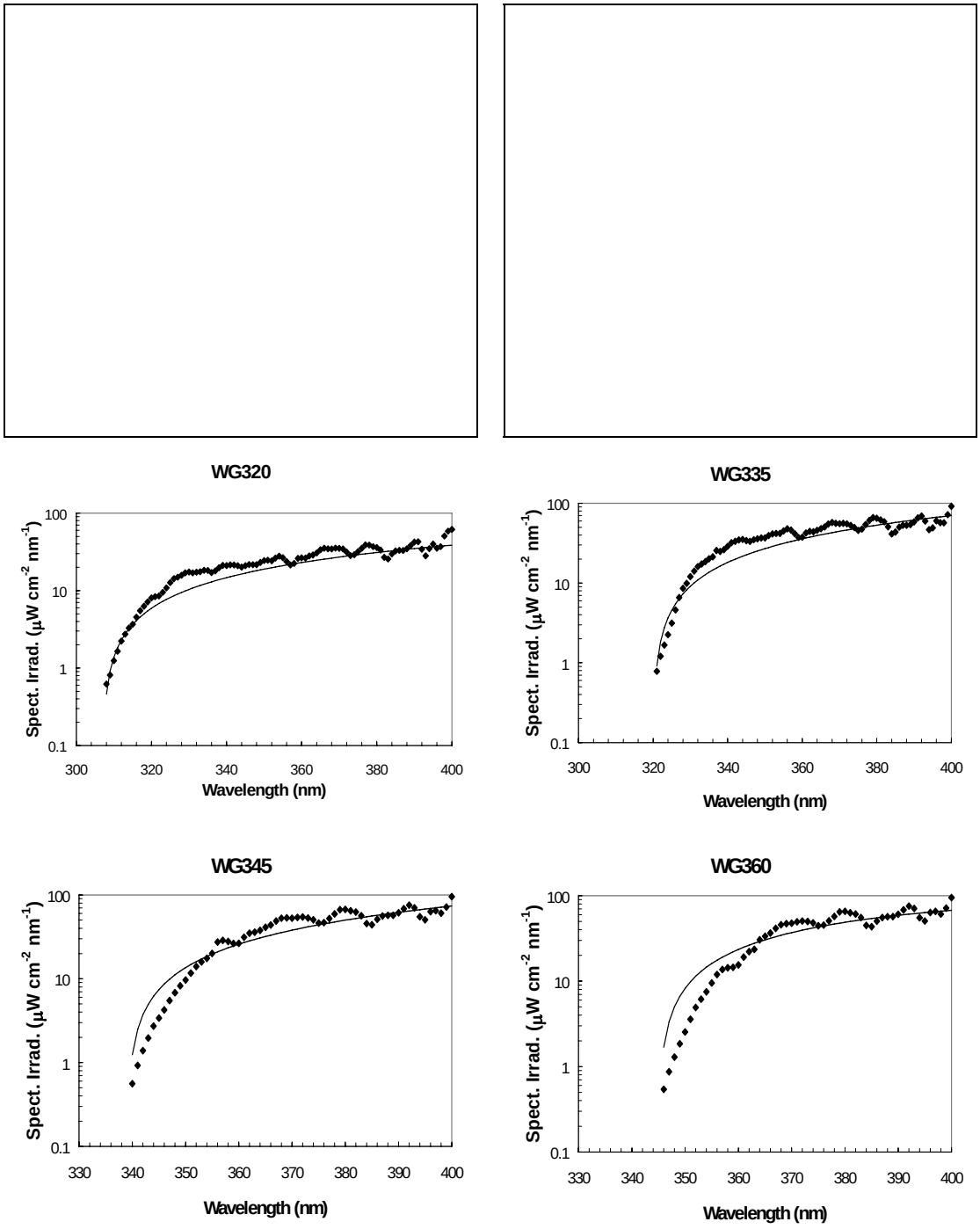
WG320
WG335
WG345
WG360
Spect. Irrad. (µW cm-2 nm-1)
Wavelength (nm)
100
10
1
0.1
300
320
340
360
380
400
330
350
370
390

Figure 6.