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The UVB content of 'UVA fluorescent lamps' and its erythemal effectiveness in human skin

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Abstract. The UVB emission from ten different types of 'UVA fluorescent lamp' has been measured by spectroradiometry. The mean ratio of UVB emission to UVA emission was found to be 0.94 ± 0.35 (1 SD)%. By weighting the spectral irradiance of each lamp by the DIN standard erythemal curve, the mean erythemally effective UVB emission (normalised to 297 nm), expressed as a percentage of the UVA emission, was 0.076 ± 0.049 (1 SD)%.

1. Introduction

In recent years the use of artificial sources of UVA radiation has increased rapidly in both the medical and consumer fields. This is due largely to the widespread treatment of psoriasis by oral psoralen photochemotherapy (PUVA), and to the increasing cosmetic use of sun-lamps, solaria, and sunbeds (Which? 1979). The most common source of UVA employed in both medical whole-body UV irradiation units and cosmetic sunbeds is the so-called 'UVA fluorescent lamp'. These lamps emit small quantities of visible, infrared, and UVB radiation in addition to the predominant UVA emission. Since the quantity of UVB radiation needed to produce erythema in normal human skin is some thousand-fold less than that of UVA radiation (Warin 1978), concern has been expressed about the quantity of biologically effective UVB which may be emitted by 'UVA fluorescent lamps'. It is therefore important to have data on the UVB emission of these lamps so that the erythemal effectiveness of the UVB component can be assessed.

The notion to divide the ultraviolet spectrum into different spectral regions UVA, B, C was put forward at the Copenhagen meeting of the Second International Congress on Light (Coblentz 1932). It was recommended that the different regions be defined as follows:

UVA 400–315 nm

UVB 315–280 nm

UVC 280–100 nm.

Various authorities including the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) in the United States, and the Health and Safety Executive (HSE) and the National Radiological Protection Board (NRPB) in the United Kingdom have, by

their use, endorsed these regions, and this convention will be adopted in this paper, although the presence of erythemally effective radiation in the region 315 to 325 nm is also considered (see below).

2. Methods

The quantity of interest in this paper is not primarily the spectral irradiance of UVA fluorescent lamps but rather the erythemal effectiveness of the UVB component. This quantity is determined by weighting each wavelength component of the lamp spectrum by its effectiveness in producing erythema and then summing (integrating) over the UVB range of wavelengths emitted by the lamp. This summation assumes that the actions of the separate spectral components are independent and combine in a simple additive manner. That is, no synergistic or protective interactions exist between radiations of different wavelengths.

Because of the uncertainty in the erythema action spectrum in normal human skin shown by Diffey (1982), the tabulated erythemal spectral efficiency data published in the German DIN standard (1978) has been chosen for the purpose of the present analysis. This data is based largely on the 'standard erythemal curve' adopted by the International Commission on Illumination (CIE 1935), the main difference being that the DIN standard decreases more rapidly than the CIE standard at wavelengths greater than 297 nm.

The erythemally effective UVB irradiance at a given point exposed to the radiation from the UVA fluorescent lamp is denoted as UVB(EE) and may be expressed mathematically as:

$$\text{UVB(EE)} = \sum_{280}^{315} E(\lambda)\varepsilon(\lambda)\,\Delta\lambda \text{ W m}^{-2} \tag{1}$$

where $E(\lambda)$ is the spectral irradiance (W m^{-2} nm^{-1}) at wavelength λ nm, $\varepsilon(\lambda)$ is the relative effectiveness of radiation of wavelength λ nm in producing erythema, and $\Delta\lambda$ is the wavelength interval (nm).

The values of the relative spectral effectiveness published by DIN (1978) and used in the present study are presented in table 1. The values extend to wavelengths up to 325 nm. This action spectrum is relative to the value at a wavelength of 297 nm and so the erythemally effective UVB irradiance given by equation (1) is equivalent to that irradiance of monochromatic 297 nm radiation which would produce the same degree of erythema in a given time as the total irradiance from the UVA fluorescent lamp given by

$$\sum E(\lambda)\,\Delta\lambda \text{ W m}^{-2}$$

where the summation is over all the wavelengths emitted by the lamp. The UVA irradiance is simply equal to

$$\sum_{315}^{400} E(\lambda)\,\Delta\lambda \text{ W m}^{-2}.$$

Similarly the UVB irradiance is given as

$$\sum_{280}^{315} E(\lambda)\,\Delta\lambda \text{ W m}^{-2}.$$

In the present study all measurements were carried out using a semi-automated prototype version of a portable scanning spectral radiometer (SSR) designed and

Table 1. Values of relative spectral effectiveness (RSE) for erythema (DIN 1978).

Wavelength (nm)	RSE	UV zone
240	0.56	
245	0.57	
250	0.57	
255	0.54	
260	0.42	UVC
265	0.25	
270	0.14	
275	0.07	
280	0.06	
285	0.09	
290	0.31	
295	0.98	
297	1.00	UVB
300	0.73	
305	0.20	
310	0.054	
315	0.015	
320	0.004	UVA
325	0.001	

constructed by NRPB. Such an instrument is not readily available commercially and is expensive to build. A schematic diagram of this instrument in its final form is shown in figure 1 and its present performance characteristics are listed in table 2. The instrument in its final automated form will be controlled by a microprocessor unit, operated by means of a miniature keyboard and will store spectral irradiance data on high speed magnetic tape cassettes. These will enable data transfer to a microcomputer (PET 8032) where calculations, including spectrally weighted summations, can be performed and graphical representations of spectra, such as shown in figure 2, obtained. The SSR's own microprocessor unit will also enable calculations on data to be made at the time of measurement and displayed on a thermal printer. At the present stage of its development the scanning is carried out automatically but the data is collected and transferred manually to the microcomputer.

The input optics of the SSR consists of an integrating diffusing sphere coated internally with Eastman Kodak Diffuse Reflectance Standard Coating 6080. This provides the instrument with a cosine and wavelength independent spatial efficiency of response over the range of wavelengths 200 to 600 nm. Wavelength scanning is achieved by a stepping motor coupled to the diffraction grating rotation mechanism of the monochromator via a precision gearbox. Optically aligned anti-backlash gears provide precise wavelength setting. Wavelength calibration is obtained using a HeNe laser (632.8 nm), an argon ion laser (514.5 and 488 nm) and a low pressure mercury discharge lamp (253.7 nm). The spectral sensitivity calibration of the instrument was obtained by reference to a National Physical Laboratory's calibrated deuterium spectral irradiance standard. The uncertainty associated with electronic and optical 'noise' is $< \pm 2 \times 10^{-3}$ V. This is equivalent to an uncertainty in spectral irradiance of 2.4×10^{-7} W m^{-2} nm^{-1} at 300 nm. The spectral irradiances of the UVA fluorescent lamps at 300 nm varied between 6×10^{-6} and 60×10^{-6} W m^{-2} nm^{-1}. Therefore for the

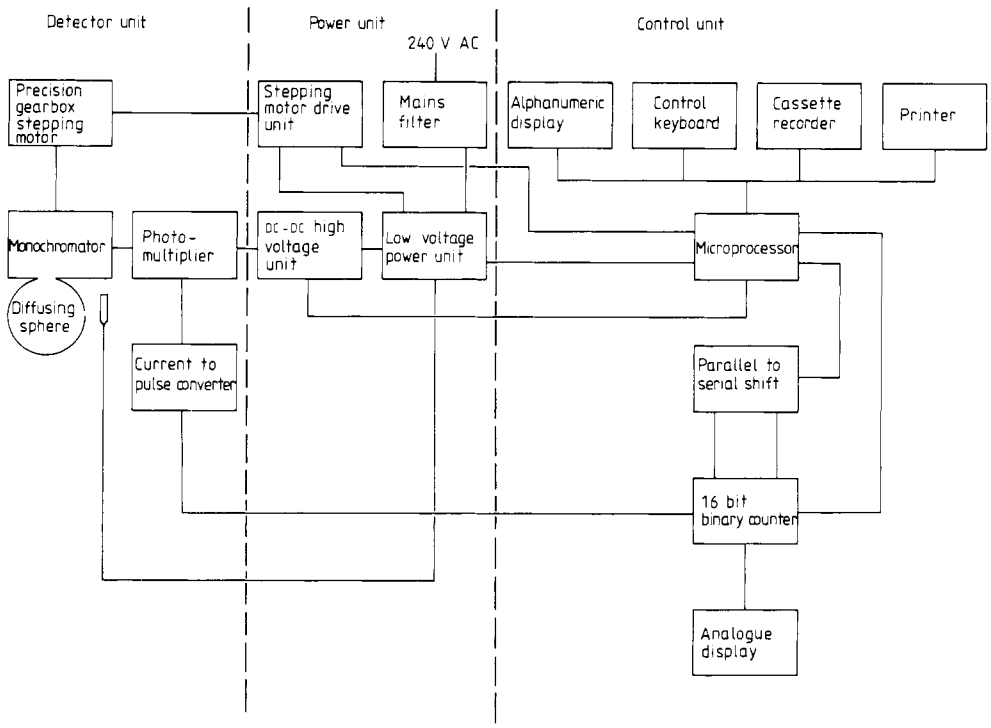

Figure 1. Schema of NRPB scanning spectral radiometer.

Table 2. Characteristics of NRPB Scanning Spectral Radiometer.

Input optics	Variable aperture (0.5 to 16 mm)
	Integrating sphere
Coating	Eastman Kodak Reflectance Standard 6080
Monochromator	Yvon Jobin Double grating
	2 reflecting surfaces only
Useful wavelength range	190–600 nm
Bandwidth range	2–10 nm
Minimum wavelength stepping increment	0.1 nm (100 control pulses per nm)
Detector	EMI Photomultiplier 9824Qb
Typical spectral sensitivity	400 nm 2.76×10^{4} V per W m^{-2} nm^{-1}
	350 nm 1.65×10^{4}
	300 nm 8.4×10^{3}
	250 nm 2.36×10^{3}
	200 nm 38
Typical background, optical + electrical (variation in brackets)	$\sim5\times10^{-3}$ V (2×10^{-3})

minimum spectral irradiances at 300 nm (i.e., worst case) the uncertainty associated with 'noise' is approximately ±5%. The uncertainty associated with sensitivity drift of the radiometer is approximately 5%. Hence the overall uncertainty between measurements is approximately ±10% (arithmetically summed). The uncertainty associated with calibration against the spectral irradiance standard is approximately ±12%. The expected overall error in the absolute values of irradiance should not be greater than 22% (arithmetically summed).

All measurements were made at a distance of 1.00 m from the midpoint of each tube. The single tubes (nominally 100 W), each from a different manufacturer, were mounted in a standard commercial 1.80 m fluorescent tube fitting. No additional reflective or filtering materials were used. Each tube was allowed to warm up for 15 min prior to the commencement of measurements. The bandwidth of the SSR was kept constant at 3 nm and a wavelength stepping increment of 1 nm was used in all measurements.

3. Results

A relative spectral irradiance plot representing the emission from an 'average' tube is illustrated in figure 2 (curve C). This was obtained by summing the measured values

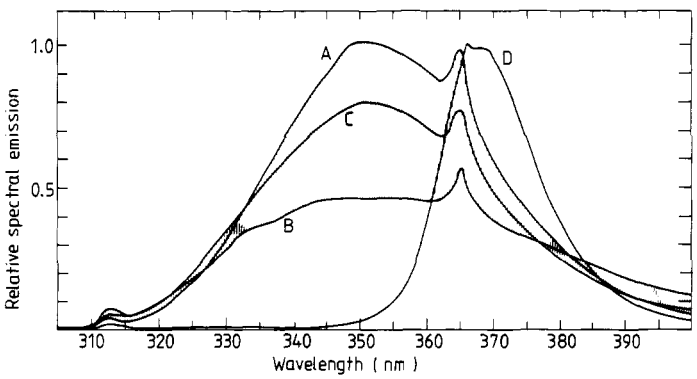

Figure 2. Plots of relative spectral irradiance (normalised to 351 nm) for; A, lamp with greatest emission at 351 nm; B, lamp with smallest emission at 351 nm; C, average lamp, and D, plot of relative spectral irradiance of lamp with fluorescent peak emission at 365–367 nm.

of spectral irradiance of all except one of the tubes at each wavelength and normalising to the value corresponding to the fluorescent peak wavelength (351 nm). The overall variations in spectral irradiance which one would expect by using a tube type chosen at random are indicated by the shaded area. This area is bounded by plots of the spectral irradiance values obtained from the tubes displaying the highest (curve A) and lowest irradiance (curve B). The absolute values of spectral irradiance of the average and lowest irradiance tubes are normalised against those of the highest irradiance tube (at 351 nm). The spectral irradiance characteristics of one of the tubes (the only 'Blacklight' tube included) was markedly different from the rest. Its fluorescent peak emission coincided with the 365–367 nm characteristic line emissions of mercury vapour. Therefore it was excluded from the averaging procedure. The spectral irradiance of this tube is shown separately in figure 2 (curve D).

A summary of the results of the spectral and spectrally weighted summations for each tube, together with the values of an 'average' tube are presented in table 3.

The erythemally effective UVB irradiance given in equation (1) was computed in 1 nm steps with the consequent linear interpolation for values of $\varepsilon(\lambda)$ from the data given in table 1.

The UVB irradiance at 297 nm was computed by summing the spectral irradiance in the wavelength interval 296 to 299 nm rather than just considering the spectral irradiance in the 1 nm interval around 297 nm. This procedure was adopted to ensure

Table 3. Summary of spectral irradiance data for 10 types of UVA fluorescent tubes.

Lamp code	Fluorescence peak (nm)	UVA ($W m^{-2}$)	UVB ($W m^{-2}$) $\times 10^2$	$\frac{UVB}{UVA}$ (%)	$\frac{UVB\ (EE)}{UVA}$ % summed to 325 nm	$\frac{UVB\ (EE)}{UVA}$ (%) summed to 315 nm	$\frac{UVB\ (297\ nm)}{total\ UVB}$ (%)	$\frac{UVB\ (EE)\ (297\ nm)}{total\ UVB\ (EE)}$ (%)
1	348–354	1.18	1.82	1.55	0.116	0.093	0.48	6.0
2	366	1.35	1.06	0.79	0.181	0.180	8.0	32
3	351	1.55	0.86	0.56	0.039	0.030	0.25	3.5
4	350	1.84	2.03	1.10	0.096	0.084	1.5	16.7
5	351/2	1.51	1.71	1.14	0.099	0.086	1.8	19.2
6	351/2	1.86	0.81	0.44	0.028	0.020	0.23	3.5
7	351/2	1.83	1.27	0.69	0.045	0.035	0.36	5.2
8	351/2	1.68	0.96	0.57	0.036	0.027	0.30	4.6
9	351/2	1.54	2.19	1.42	0.149	0.135	2.2	19.7
10	350–357	1.17	1.29	1.10	0.088	0.072	0.7	8.1
Mean	—	1.55	1.40	0.94	0.088	0.076	0.87†	9.6†
Coefficient of variation (%)	—	16	34	37	56	64	82	67

† Lamp 2 omitted.

that the irradiance due to the 297 nm characteristic mercury spectral line was adequately evaluated and reflected the uncertainty of 0.4 nm in the wavelength positioning of the monochromator. The erythemally effective UVB irradiance at 297 nm was determined in a similar manner by applying the interpolated values of $\varepsilon(\lambda)$ at 296, 297 and 298 nm to the spectral irradiance values at these wavelengths and summing the products over the 3 nm wavelength interval.

4. Discussion

The variation in the overall UVA irradiances of the 10 tubes is relatively low (coefficient of variation 16%) compared with the variation in UVB (34%). Below 315 nm the spectral emissions from all of the tubes fall off very sharply and the characteristic mercury vapour lines at 313 nm and 297 nm comprise almost all of the radiation emitted, resulting in a mean UVB emission of 0.94% of the UVA. Similarly, the erythemally effective UVB(EE), expressed as a percentage of the UVA emission and normalised to 297 nm (the peak of the CIE and DIN Standard Erythemal Curves) is low (0.076%). As the values of erythemal efficacy extend to 325 nm an additional calculation was made to assess the change in UVB(EE) which would result from extending the weighted summation to 325 nm. These results are also presented in table 3 (mean value 0.088%). The minor change in the weighted summation is indicative of the very low values of erythemal efficacy between 315 and 325 nm.

With the exception of lamp 2, the ratio of UVB emitted at 297 nm to total UVB emitted is low (0.87%)—table 3. However because of the relatively high erythemal weighting factors around 297 nm the ratio of erythemally effective UVB emitted at 297 nm is significant (9.6%) compared with the total UVB. For lamp 2, 32% of the erythemally effective UVB is emitted at 297 nm.

Only one example of each type of lamp was available for measurement. All of the lamps measured appeared to be 'new' and had not suffered ageing. At present we have no knowledge of the variations in spectral emission, particularly in the UVB, among batches of nominally identical lamps supplied by a single manufacturer. However, the observed variations among lamps from different manufacturers are relatively small.

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Résumé

Le contenu en UVB des lampes à fluorescence UVA. Ses effets érythémateux sur la peau humaine.

Nous avons mesuré par spectrométrie l'émission UVB de dix types de 'lampes à fluorescence UVA' différents. Le rapport moyen émission UVB/émission UVA est de 0,94 ± 0,35% (1 écart type). Par pondération de l'irradiance spectrale de chaque lampe par la courbe érythémateuse du standard DIN, l'émission UVB moyenne érythémateuse (normalisé à 297 nm), exprimée en pourcentage de l'émission UVA, est de 0,076 ± 0,049% (1 écart type).

Zusammenfassung

UVB-Gehalt von UVA-Fluoreszenzlampen und Erythemwirkung auf menschliche Haut.

Die UVB-Emission von 10 verschiedenen UVA-Fluoreszenzlampen wurde mit Hilfe der Spektroradiometrie gemessen. Dabei lag das mittlere Verhältnis zwischen UVB- und UVA-Emission bei $0.94 \pm 0.35\%$. Nach Wichtung der spektralen Strahlungsdichte von jeder Lampe mit der DIN-Standarderythemkurve betrug die mittlere erythemwirksame UVB-Emission (normiert auf 297 nm), ausgedrückt in Prozent der UVA-Emission, $0.076 \pm 0.049\%$.

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