Acta Dermatovener (Stockholm) 55: 261–271, 1975

DEVELOPMENT OF HIGH INTENSITY NARROW-BAND LAMPS AND STUDIES OF THE IRRADIATION EFFECT ON HUMAN SKIN

Irradiation with High Intensity Lamps

Jan Alsins, Stig Claesson, Torkel Fischer and Lennart Juhlin

From the Departments of Physical Chemistry and Dermatology, University of Uppsala, Uppsala, Sweden

Abstract. A compact light source has been developed. It consists of a high-pressure mercury lamp, a shutter, and water-cooled filters for selected wavelength regions. A mixing device permits simultaneous irradiation from two lamps of different wavelengths. The spectral distribution of the light for seven filter combinations and the construction of a power meter are also described. The application of the lamps to clinical investigations is illustrated by determination of minimal erythemal and blister doses, as well as pigmentation, for various groups of patients. The light intensities available are high enough to make pain threshold measurements possible in the UV and visible regions.

Key words: Lamp construction; Light test; Photosensitivity; Skin reactions; UV-rays

Interest in the reactions of skin to light has led to the development of various types of irradiation and test equipment. In 1921 Hausser & Vahle (6) used spectrally isolated light in their studies of erythema formation and pigmentation. Their apparatus was a medium pressure mercury lamp in combination with a quartz spectrograph. The interest in action spectra led to the construction of high flux monochromators for use with continuous light sources. In 1959 Magnus et al. (11) built a water-prism monochromator and used it in combination with a xenon lamp. A description of a recently designed apparatus and a review of similar instrumentation has been given by MacKenzie & Frain-Bell (10). Equipment containing a high pressure xenon lamp and glass filters for isolating wavelength regions of interest has been used by Wiskeman & Wulff (19) and Turnbull et al. (18). Rottier used a Philips SP 500 W high pressure mercury arc lamp and interference filters to isolate the lines at 366, 405, 436 and 546 nm (17) and a small quartz spectrograph with an HPK 125 W mercury lamp for the UV-part of the spectrum (16). The main advantage of mercury lamps is the high intensity at the line wavelengths.

In this publication we describe a new type of lamp-housing for the SP 500 W lamp with water-cooled filters where the distance from the capillary lamp to the irradiated area can be as small as 30 mm. This short distance makes it possible to obtain high irradiances. An area as large as 3.8 cm² can be irradiated with a uniform light intensity. Such a size is advantageous for experiments with repeated irradiations on the same spot. A diseased skin is not homogeneous and the effect of light treatment may be difficult to interpret if the test area is too small. The maximum power available is 150 mW/cm² or more depending on wavelength region selected. For the testing of skin reactions, intensities were chosen to give irradiation times ranging from 5 seconds to 5 minutes.

GENERAL DESCRIPTION

The lamp housing

For achieving high light intensity at moderate electric input power, it is most suitable to use a small lamp of high radiance and irradiate the object at close quarters. The water-cooled SP 500 W lamp is a convenient light source for such purposes. The diameter of the arc is 2 mm and the length is 12.5 mm.

The high light intensities used in our work make it necessary to water-cool the filters used for isolation of the spectral regions—they would otherwise crack within a few seconds. The distance to the object is made small by incorporating the filters into the lamp housing and using the cooling water for the lamp to cool the filters on its return path. Frequent switching on and off affects the stability and lifetime of the lamps. Therefore a thin, rotating, cylindrical metal shutter is mounted between the lamp and the filters. Thus, with lamp and cooling water running continuously, the filters are only exposed to light when the shutter is opened for irradiation.

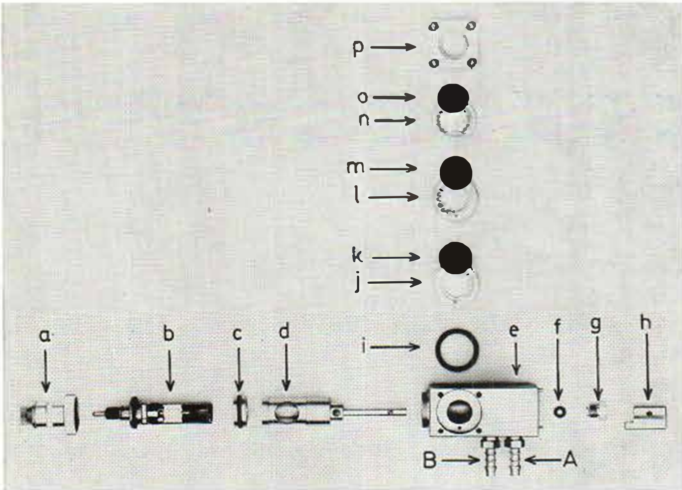

Fig. 1a. Photograph of the lamp housing and its parts, top view. (*a*) electric connector, (*b*) lamp with reflector, (*c*) guard ring, (*d*) shutter with stem, (*e*) main body, (*f*) O-ring, (*g*) hollow bolt, (*h*) shutter handle, (*i*) soft O-ring, (*j*, *l*, *n*) flow directing and filter holding rings, (*k*, *m*, *o*) filters, (*p*) lid, (*q*) cross-bore in the shutter, (*r*) flow directing quartz cover glass, (*s*) arc, (*t*) openings, (*u*) groove.

This reduces the deterioration of the filters considerably. No optical elements other than the filters are used. The intensity is varied by altering the distance between the lamp and the irradiated area with blackened brass tubes of different lengths. A photograph of the components of the lamp housing is seen in Fig. 1*a* and a schematic drawing from the side is seen in Fig. 1*b*. The dimensions of the lamp housing are 4 × 4 × 10 cm. The cone of light emerging at the top filter (*o*) is 20 mm in diameter and half the apical angle is approximately 17 degrees. In Fig. 1*b* the waterflow in the lamp housing is indicated by the dashed line. The water enters at (*A*), flows through the crossbore (*q*) in the shutter (*d*) and is directed along the capillary arc (*s*) by a quartz cover glass (*r*). The water emerges through the openings (*t*) into the shutter (*d*), passes through the opening of the shutter and is directed along the filters by the holding rings (*j*), (*l*) and (*n*) to the exit (*B*). The ring (*l*) has a guiding pin which ensures correct positioning of the rings in relation to the outlet. When the shutter is closed, the opening is below the capillary arc (*s*) and the water reaches the filters and the outlet by the groove on the outside of the shutter seen at (*u*).

Lamps mounted for irradiation are seen in Fig. 2*a* and *b*. The blackened brass tubes (*a*) are used to obtain a suitable intensity at irradiation. They are threaded at one end and are screwed into the lid. The inner diameter of the tube is 22 mm. To obtain smaller areas, conical end-pieces are placed on the end of the tube. The insides of the conical end-pieces are painted black and measurements with the power meter have verified that the irradiance is the same as that at the end of a cylindrical tube of the same height. The cones have the advantage that small spots can easily be located for irradiation. Opening diameters of 3, 7 and 10 mm have been found suitable for non-repetitive light tests.

It is convenient to have one lamp for each wavelength, as filter changes are thus eliminated and simultaneous irradiation with different wavelengths can be performed. This is done with the mixing-device shown in Fig. 3*a* and *b*. The geometric design of the mixer involves the intersection of two irradiation tubes. As the circular head of the power meter cannot fit on the elliptic opening of the mixer, the mixer has two interchangeable top-pieces fastened with a snap-lock. The top-piece (*c*) is used for irradiation and top-piece (*d*) for intensity measurements. The intensity is meas-

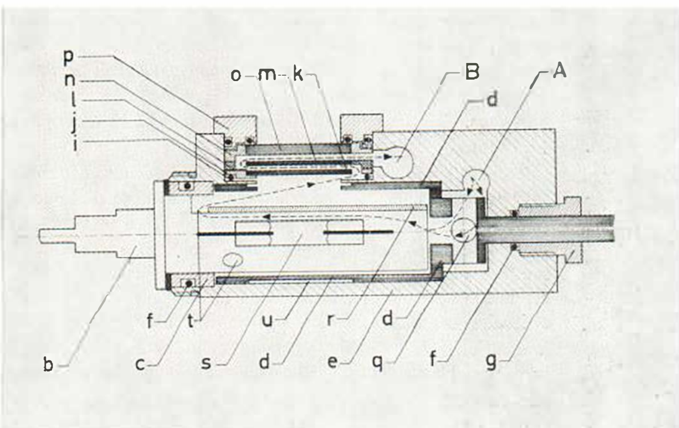

Fig. 1b. Schematic drawing of the lamp housing, horizontal view. The flow of water is indicated by the dashed line. For explanation of symbols, see Fig. 1*a*.

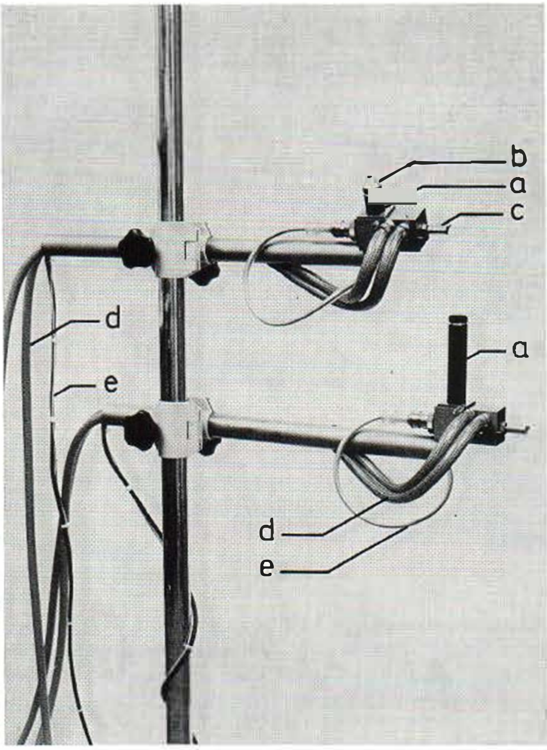

Fig. 2a. Two lamps mounted for irradiation. (*a*) irradiation tube, (*b*) conical end-piece, (*c*) shutter handle, (*d*) plastic tubing for cooling-water, (*e*) electric cable.

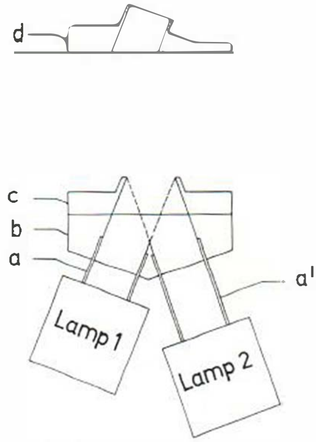

Fig. 3a. Schematic diagram of the light mixer. The lamps with brass tubes (*a* and *a'*) fit into the lower part of the mixer (*b*). The top piece (*c*) is used at irradiations and is substituted by the top piece (*d*) at power measurements, which are made perpendicular to one lamp at a time.

ured perpendicular to one lamp at a time when the shutter of the other is closed. The top-piece (*d*) can therefore be turned 180 degrees. The readings are multiplied by 0.94, which is the cosine for half the apical angle (20°) of the conical cross section in Fig. 3*a*. The intensity can be varied independently for the two wavelengths by using different tube lengths.

The mounting

The 450 V a.c. operating voltage to the SP 500 W lamp is supplied by a high reactance transformer, Philips 59300 BE/01, which can be run on a.c. mains from 105 V to 380 V. Six transformers with individual switches are mounted on a carriage and a resettable meter for measuring lamp operation hours is connected parallel to each transformer.

The cooling water passes through a ceramic filter and the lamps connected in series. A flow-switch in the return path supplies current to a self-holding circuit of a relay that connects the mains to the transformers. Should the water flow drop below the required 4 l/min, the flow-switch disconnects the relay which can be restarted manually when flow is normal again.

The lamps are mounted on stands as seen in Fig. 2*a*. The arc must be operated in a horizontal position and is parallel

Fig. 2b. Irradiation of a patient.

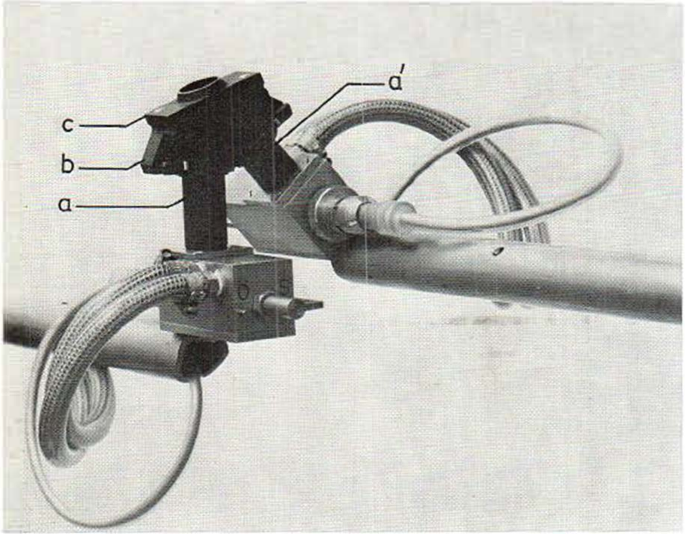

Fig. 3b. Photograph of the light mixer with two lamps. For explanation of symbols, see Fig. 3*a*.

to the tube on which the lamp is mounted. The plastic tubings for the cooling water and the electric cables also pass through this tube. The lamp can be moved up and down on the stand and can be rotated about the axis of the horizontal tube. In this way, access to all parts of the patient's body is easily obtained.

Filters and spectral distribution of the light

The spectrum of the SP 500 W mercury lamp is shown in Fig. 4. Isolation of the wavelength bands can be made with interference or glass filters. Until recently, interference filters in the 200–350 nm range had low transmission, 0.15–0.20, due to the absorption by the dielectric coating. The bandwidth at 1% of peak transmission was approximately 150 nm. New dielectrics have increased the transmission and decreased the bandwidth. Interference filters are manufactured with the peak transmission within a few nm of the required maximum, which can be in the region from 180 nm to infrared. Combinations of glass filters are limited by the number of long wavelength cut-off filters, but good combinations for the isolation of the mercury lines can be selected. After prolonged irradiation with UV-light, glass and interference filters change transmission characteristics and should be replaced.

The glass filters used for the isolation of the mercury

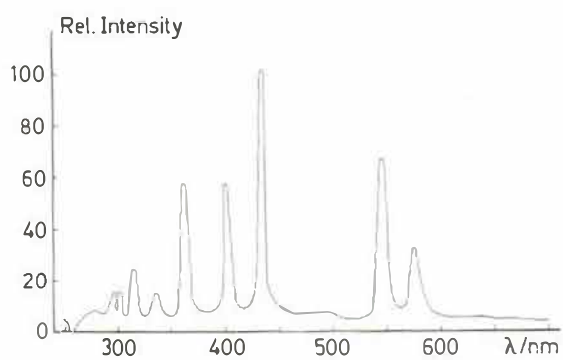

Fig. 4. Spectral distribution of the light from the SP 500 W mercury lamp (relative intensity per nm).

Table I. *Filters for isolating the mercury lines*

For some cut-off filters the short wavelength limit varies within a melt. Others are more constant but vary between different melts. Therefore the wavelength for 0.50 transmission measured against air is specified. Schott filters are used unless otherwise specified

Combination	Line (nm)	Filters
A	313	WG 305 (4 mm), $T = .50$ at 307 ± 1 nm UG 11 (2 mm) GG 19 (1 mm)
B	334 + 365	WG 345 (2 mm), $T = .50$ at 336 ± 1nm UG 11 (2 mm)
I	334	UV–PIL interference filter with B as prefilter
C	365	WG 360 (3 mm), $T = .50$ at 357^{+2}_{-1} nm UG 11 (1 mm)
D	405	GG 400 (1 mm), $T = .50$ at 394^{+4}_{-3} nm BG 38 (2 mm) Corning 5970 (1.3 mm)
E	436	GG 435 (1 mm), $T = .50$ at 430 ± 2 nm BG 25 (2 mm)
F	546 + 577/9	OG 530 (2 mm), $T = .50$ at 526 ± 1 nm BG 18 (2 mm)

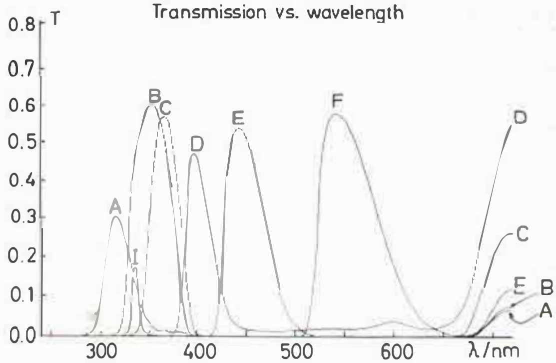

Fig. 5. Transmission of the filter combinations used to isolate the bands from the mercury lamp.

lines are specified in Table I. The transmission for the various combinations is shown in Fig. 5. Special care has been taken to minimize unwanted stray light on the short wavelength side. The spectral distribution of the light that has passed through the filters is shown in Fig. 6*a*, *b* and *c*. It

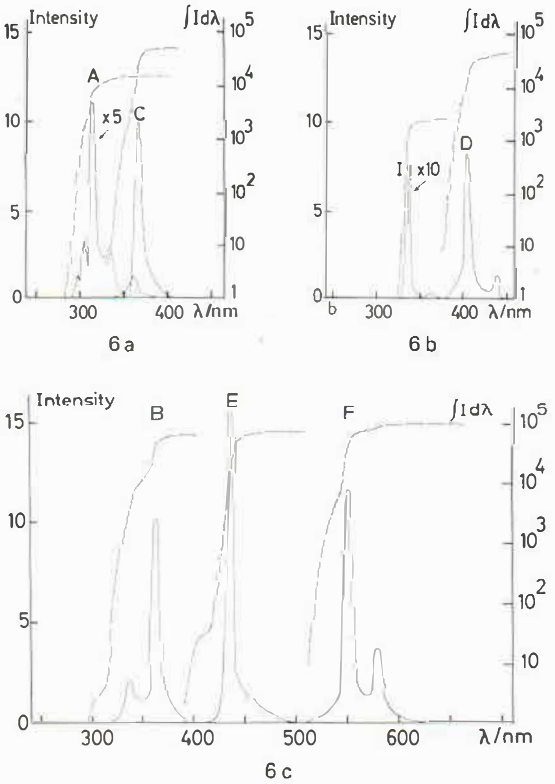

Fig. 6a, b, c. ——, Spectral distribution of the light after having passed the filter combinations. The intensity per nm is given in relative units, same for all combinations. The distribution curves for A and I are enlarged five and ten times respectively. - - -, Integrated intensity, ∫Idλ, as a function of the wavelength starting from the short wavelength side of the distribution curve.

has been calculated by multiplying the transmission of the filter combinations with the spectral distribution of the lamp. The total intensity in relative units is obtained by integrating the spectral distribution curve. Starting from the short wavelength end, integration with the trapezoid rule is carried out and the area is plotted as a function of the wavelength. This gives an estimate of the spectral purity on the short wavelength side of the spectral distribution curve. Thus for filter combination C, (Fig. 6*a*) the intensity of the light of wavelengths shorter than 330 nm is 4 relative units and for the light shorter than 365 nm, 2×10^4 relative units, thus, their ratio is 2×10^{-4}.

The filters in combination A have been selected so that the short wavelength part of the natural ultraviolet radiation from the sun is simulated. The ratio of the intensities at 290 and 310 nm is 4×10^{-3} which can be calculated from Fig. 6*a*. From Bener's measurements of the ultraviolet sky radiation in Davos (1), a ratio of 0.2 for the intensities at 297.5 and 300 nm is calculated from a spectrum where the solar altitude is 50°. The ratio for the A combination is 0.5.

The maximum irradiance available for the different bands is listed in Table II.

The power meter

The field of view for most commercial power meters is only a few degrees. A correct reading would not be obtained if used directly on our lamps where the angle of incidence varies from 0 to 17 degrees for different rays. A sensing head with quartz diffusers for this range has been constructed and is seen in Fig. 7*a* and *b*. The light-sensitive element is a schottky pin photodiode, PIN-10 UV from United Detector Technology Inc., USA. The spectral response is seen in Fig. 8. The intensity response to a given wavelength is linear for intensities from 10^{-11} to 10^{-3} W/cm². The upper limit can be exceeded 900 times by the 546+577/9 nm band. An attenuation of 1 000 times was therefore provided by introducing quartz diffusers and apertures (pinholes).

The pinholes were made in 1 mm brass plates and are conical to permit the divergent light to pass. The diffusers are 2 mm quartz plates ground on both sides. The detector fits on the irradiation tubes and when the conical end-pieces are used they are replaced by a cylindrical tube of the same height for power measurements.

The pin diode is operated in the photoconductive mode. A stepdown transformer, a rectifier bridge, and a smoothing capacitor supply a 22 V reverse bias voltage to the diode in series with a 10 kΩ resistor and a Cambridge spot galvanometer. The resistance of the galvanometer coil is 450 Ω and full-scale deflection is obtained at 0.90 μA. After calibration, the galvanometer scale is set to read irradiance in mW/cm² by switching in a shunt resistor for each wavelength band across the 10 kΩ resistor and the galvanometer. Using the decade shunt of the galvanometer, full-scale deflection is obtained for 10, 100, or 1 000 mW/cm².

Calibration procedure

The power meter system was calibrated with the ferrioxalate actinometer (5). Irradiation times in the order of 1 minute were used to minimize errors in time caused by opening and closing of the shutter. To obtain a well defined area and to prevent excessive decomposition of the actinometer solu-

Table II. *Maximum irradiance on an area of 3.8 cm² with the different filter combinations*

Filter combination	A	I	B	C	D	E	F
Band maximum, nm	313	334	334+365	365	405	436	546+577/9
Irradiance, mW/cm²	150	10	350	300	200	450	900
Fraction of power meter reading due to red light	.13	.00	.076	.34	.084	.061	.013

tion, a 0.1 mm thick circular disc with a precision bored hole (4.05 mm in diameter) in the centre was used. A 5 cm cylindrical quartz cuvette containing 10 ml of ferrioxalate solution was placed vertically on the disc which was positioned by a ring on the irradiation tube. Before the actionometer solution was irradiated, the intensity was monitored with the power meter for 10 min. With new lamps, the intensity was constant within $\pm 0.2\%$. The mean values of the intensity and the dark current immediately before and after the irradiation (1–10 min) were used in the calculations. Four measurements at different intensities were normally made for each filter combination. The galvanometer response as a function of the irradiance, calculated from the change of the ferrous ion concentration in the actinometer was linear. The slope was used to calculate the shunt resistance that was necessary to obtain the proper irradiance reading from the galvanometer scale. When the wavelength shunts were installed, the irradiance reading from the galvanometer and the actinometer were compared in a final test. The readings agreed within $\pm 3\%$ for all wavelengths. After one year of operation, the meter readings were still within the tolerances of the original calibration.

The sensitivity of the ferrioxalate actinometer decreases rapidly at 550 nm. The intensity at the 546+577/9 nm band was calculated from the attenuation at 405 and 436 nm and the spectral response curve for the pin photodiode (Fig. 8).

Filter- and lamp-ageing

The filter combinations have a second transmission band starting at approximately 650 nm, as is seen from Fig. 5. The continuum from the mercury lamp gives a small amount of red and infrared light that is transmitted to 1.3 μm; for longer wavelengths the cooling water absorbs the infrared radiation. The power meter responds not only to the isolated bands in UV and visible but also to the red and infrared radiation (Fig. 8 and Table II). The ferrioxalate actinometer is insensitive to red and infrared light. The calibration of the power meter is such that only that fraction of the radiation which corresponds to the UV or visible part is considered. It is therefore important that the relative shape of the absorption curves of the filters remain constant. This is checked with a cut-off filter, Schott RG 610 (2 mm), that only transmits the red and infrared light. As long as the ratio of the galvanometer readings with and without this filter are constant, the filter combination can be used. Also, careful cleaning at regular intervals is necessary to remove deposits which, like a grey filter, could otherwise reduce the transmission by a factor of 10 or more.

The decrease in UV transmission of the filters caused by prolonged exposure to UV-light (9) is minimized by the fact that the shutter between the lamp and the filters is open only during irradiations. After 15 hours of effective irradiation of

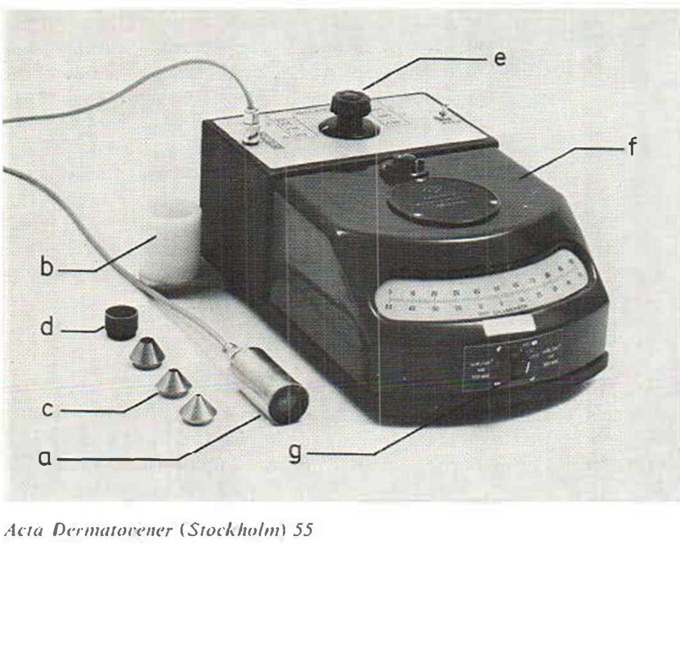

Fig. 7a. Photograph of the power meter. (*a*) sensing head, (*b*) holder for sensing head, (*c*) conical end-piece, (*d*) cylindrical tube with the same height as the conical end-pieces, (*e*) switch to select shunt corresponding to wavelength used, (*f*) galvanometer, (*g*) decade shunt.

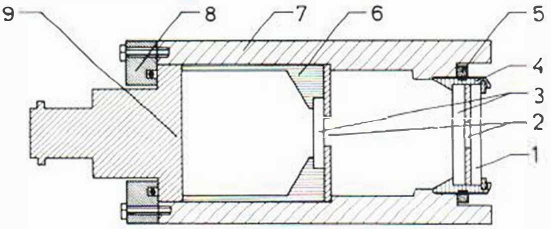

Fig. 7b. Schematic diagram of the power meter head. (1) quartz window ground on the inside, (2) apertures, (3) quartz diffusers ground on both sides, (4) adjustable mounting to fix the entrance aperture in the same plane as the end of an irradiation tube, (5) locking ring, (6) holder for inner diffuser, (7) housing, (8) lid with O-ring for dust protection, (9) pin diode.

patients, which corresponds to about a thousand irradiations, slight changes in some filters could be seen when checked in a spectrophotometer. The filters are therefore replaced after this interval.

The lifetime of the lamps varies considerably but is on the average 50 hours. In the spectral regions used, we have not noticed any other influence from the lamp darkening than an overall decrease in intensity.

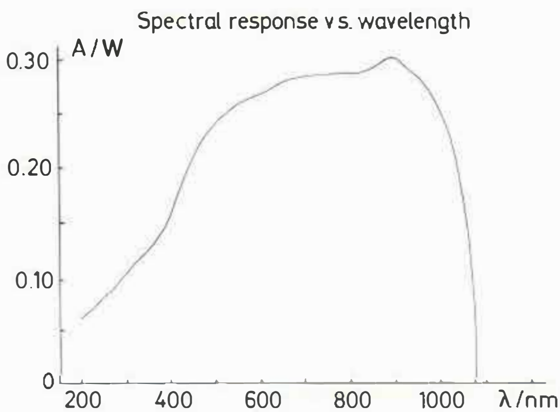

Fig. 8. Spectral response of the photodiode PIN-10 UV.

BIOLOGICAL EFFECTS

Determination of minimal erythemal dose (MED) and minimal blister dose (MBD)

The minimal erythemal dose (MED) with the 313 nm band (Filter A) was determined on the skin of the shoulder region of the back, using conical end-pieces (0.7 cm diam.) with a light intensity of 30–50 mW/cm². The following doses were given, dose (J/cm²) = intensity (W/cm²)·time (s): 0.10, 0.15, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0, 1.5 J/cm² and sometimes also 2.0, 3.0, 4.0, 6.0, and 8–10 J/cm². The irradiation times were generally less than 50 seconds and the whole series could be completed in about 5 minutes. The reactions were determined after 6–8, 24, and 48 hours and rated as follows:

0 = no erythema
1 = doubtful, hardly recognizable erythema
2 = weak but definite erythema
3 = marked erythema
4 = marked erythema with minimal edema
5 = marked erythema with marked edema
6 = bullous reaction

The minimal dose that gives a grade 2 reaction at 24 hours has been used as the MED instead of the more commonly used grade 1 at 8 hours. With the 313 nm band the grade 2 erythema is more constant and easier to evaluate than the grade 1 at 8 hours and, in addition, the MED evaluated this way is usually the same at 8 and 24 hours, and often even at 48–72 hours (7).

The minimal blister dose (MBD) can be determined with light of the 313 nm band. The bullae (grade 6) normally appeared after 24 to 48 hours.

Light of wavelengths longer than 320 nm (irradiation intensities below the endurable pain threshold) does not normally produce blisters and only a few patients have late erythemal reactions. As a result, a larger tube diameter (2.2 cm) can be used to increase the accuracy of the rating without any unpleasant effect for the patient.

Determination of recognizable-pain threshold (RPT) and endurable-pain threshold (EPT)

The pain thresholds were determined by irradiation for up to 5 minutes with different intensities and accomplished by using tubes of various lengths. The minimal intensity giving a prickly-pain sensation occurring after 1–2 minutes was used as the RPT. The maximum intensity that the patient can tolerate is the endurable-pain threshold.

Patients

During 1973–1974, 115 patients between the ages of 11 and 82 years were tested for MED on normal-appearing skin areas (Table III). In some patients the RPT and EPT were also determined. Most of the tests were carried out during September to April, the period when there is little natural UV-light in Uppsala (60° north). The patients have been grouped into three categories:

1. Psoriasis (45 patients).
2. Polymorphic-light eruption—PLE (14 patients).
3. Other dermatoses (eczema, 20; vitiligo, 6; urticaria, 5; acne vulgaris, 5; various other dermatoses, 20).

RESULTS

The 313 nm band (Filter A)

Dose effect. The minimum doses giving erythema (MED) in the 115 patients tested are shown in Table III. The logarithmic means and standard deviations for the groups are presented in Table IV. The MED of the 313 nm band is 0.2 to 1.5 J/cm² for most patients but was lower in 4 light-sensitive patients. The logarithmic mean MED was 0.50 J/cm² for the psoriasis group, 0.32 J/cm² for the polymorphic

Table III. *Minimal erythemal dose with the 313 nm band for 115 patients*

MED (Joule/cm²)	Number of patients		
	Psoriasis	PLE	Other dermatoses
0.05	0	1	0
0.10	0	1	0
0.15	0	0	2
0.2	6	2	3
0.3	11	4	17
0.4	6	2	12
0.6	10	2	14
0.8	4	0	3
1.0	3	1	4
1.5	3	1	1
2.0	1	0	0
3.0	1	0	0
Totals	45	14	56

light-sensitive group, and 0.43 J/cm² for the other dermatoses.

Irradiation with high doses of the 313 nm band results in a blister reaction. When the MED is normal or low, blistering appears at 10–20 × MED but, when the MED is high, blistering appears even with doses of 5–10 × MED (Table V). Six patients (nos. 15–20) with signs of liver disease, which was due to increased alcohol consumption in most cases, appeared to have normal MEDs but the blistering dose was only 3–7 × MED.

Size of irradiated area. The importance of the size of the irradiated area for the MED was studied in 10 patients. The erythema thresholds for diameters of 0.4, 0.7, 1.0 and 2.2 cm were determined. The MED was the same for the different diameters.

MED in various locations. Eleven patients were tested to determine the erythema thresholds for the arm, shoulder, and never-sun-exposed gluteal region. There was no great difference between the MED of the shoulder and that of the gluteal region, but that of the arm was usually higher (Table VI).

Table IV. *Mean and standard deviation of erythema threshold (J/cm²) with the 313 nm band (Filter A) for 45 patients with psoriasis, 14 patients with polymorphous light eruption and 56 patients with other dermatoses, with the assumption of a logarithmic distribution*

Diagnosis	$-3s$	$-2s$	$-s$	$\bar{X}$	s	$2s$	$3s$
Psoriasis	.070	.13	.26	.50	.97	1.89	3.68
PLE	.024	.06	.14	.32	.77	1.84	4.40
Other dermatoses	.096	.16	.26	.43	.70	1.16	1.91

The 334 + 365 nm band (Filter B)

The intensity used with these wavelengths was 100 mW/cm², which is below the RPT (150 mW/cm²). In 80 patients, a skin area of 2.2 cm diam. (3.8 cm²) was irradiated with 30 J/cm², and an immediate pigmentation and slight redness could be noted in most cases. These both fade after 1/2 to 1 hour. A slight erythema reappears in 50% of the patients after 6 to 8 hours. This lasts for about a day and leaves a weak pigmentation. Repeated daily irradiations on the same spot for 2 to 3 weeks with 30 J/cm² result in a very pronounced pigmentation with no or only a slight erythema reaction.

The 365 nm band (Filter C)

The recognizable pain-threshold intensity was between 80 and 150 mW/cm² (irradiated area 2.2 cm diam.). Pain that is slightly above the threshold level is often felt for 1 to 2 minutes and then disappears despite continued irradiation. The endurable-pain threshold level (EPT) was determined in 16 patients and found to be 20 to 50% higher than their RPT.

The maximal intensity with this filter is 300 mW/cm² and, when 4 patients were tested with it, they experienced an immediate, prickly and burning sensation that could be endured for 10 to 20 seconds. This dose corresponds to 3–6 J/cm² and gave an immediate erythema but there were no signs of recurring inflammation.

60 patients were irradiated with 30 J/cm² (100 to 150 mW/cm²). In almost all cases, a slight immediate erythema and pigmentation that disappeared within 1 hour was noted, but after 24 hours there were 4 patients, 2 of whom were diagnosed as PLE, who had a pronounced erythema, and 10 patients had a slight erythema. There was also a slight pigmentation noted after 24 hours in 10 patients, 2 of whom also had a slight erythema. Daily irradiation on the same spot with 30 J/cm² for 2 to 3 weeks will, as a rule, give rise to a marked pigmentation but not as strong as that seen in the same experiment with the 334 + 365 nm band.

The 405 nm band (Filter D)

The RPT with this light is 100–140 mW/cm². When the heat filter BG 38 is removed, the IR-radiation becomes about four times more intense than the

Table V. *MED, MBD and the relation between these values in 20 patients*

Patients 1–14 had no known liver disease. Patients 15–20 had acute liver intoxication

Pat.	MED (J/cm²)	MBD (J/cm²)	Ratio MBD/MED
1	0.2	3.0	15
2	0.2	3.0	15
3	0.2	4.0	20
4	0.3	6.0	20
5	0.3	4.0	13
6	0.4	4.0	10
7	0.6	8.0	13
8	0.6	5.0	8
9	0.8	8.0	10
10	0.8	10.0	12
11	1.0	8.0	8
12	1.5	10.0	7
13	2.0	10.0	5
14	2.0	10.0	5
15	0.3	1.5	5
16	0.6	2.0	3
17	0.3	1.5	5
18	0.3	2.0	6–7
19	0.4	2.0	5
20	0.3	2.0	6–7

UV radiation at the 405 nm band and the RPT is 80–120 mW/cm², which can be assumed to be caused by the 405 nm band plus 300 to 450 mW/cm² of infrared radiation. With this heat filter removed, blisters occur at intensities somewhat higher than the RPT. Blisters did not occur even at high intensities when using the BG 38 filter.

80 patients were tested with a dose of 30 J/cm² (70–90 mW/cm²) on the dorsal shoulder, with the BG 38 filter removed. Immediately after irradiation, the skin was strongly erythematous and slightly pigmented. These reactions disappeared after a few hours and no recurrence was seen at 24 hours. Repeated irradiation on the same spot for 2 to 3 weeks did not result in any pigmentation.

Table VI. *Comparison of the MEDs for different areas of the body in 11 patients*

Patient	MED J/cm² Lower under arm	Upper back shoulder	Lower back gluteal region
21	0.8	0.6	0.4
22	0.4	0.3	0.3
23	3.0	2.0	0.8
24	1.5	0.6	0.6
25	1.5	1.0	0.8
26	0.8	0.3	0.3
27	1.5	1.0	1.0
28	0.8	0.2	0.2
29	0.6	0.6	0.3
30	2.0	0.2	0.2
31	0.8	0.4	0.3
Mean (log)	1.06	0.51	0.41

DISCUSSION

The 313 nm band

The MED of the 313 nm band in this study does not differ much from earlier reports (4, 10, 12, 14). Magnus (12) gave a mean value of 0.4 J/cm² for a band centred at 310 nm, while Mackenzie & Frain-Bell (10) reported 0.27 J/cm². The slightly higher value reported in this investigation may be due to spectral differences and/or a somewhat different evaluation of the MED. The observed increased scatter of the erythema threshold for the patients with polymorphic-light eruption when compared with the control group also verifies earlier observations (12).

The MED was the same for areas from 0.12 to 3.8 cm². Our results support the earlier findings that one must go down to extremely small field dimensions before observing a change in the MED (13).

With the 313 nm band, large doses of light will cause blisters in the skin. The minimal blister dose (MBD) seems to vary less between patients than does the MED. It is interesting to note that, despite a normal MED, the MBD was found to be lowered in patients with liver disease. This finding needs further study.

The 334, 365 nm and 405 nm bands

With light from these bands, high doses produce an immediate erythema and pigmentation that disappears within an hour. This is in agreement with earlier results (3). The recurring erythema seen in some patients with the 365 nm band must be associated with the longwave UV light since light below 330 nm is less than 6 mJ/cm² when the total dose is 30 J/cm² (Fig. 6*a*). With the 313 nm band, these patients had a MED of about 400 mJ/cm². A delayed erythema from light of the 365 nm band has been described earlier when using a monochromator (12). No mention was made, however, of the amount of stray light shorter than 330 nm.

The recurrence of erythema with the 334 + 365 nm band in half of the patients might be due to UV light shorter than 320 nm. The light dose in the 300 nm region was about 30 mJ/cm² when a total dose of 30 J/cm² was given (Fig. 7). It cannot be excluded that this is sufficient to give a slight erythema. The integrated spectral-distribution curves are here of great value when estimating the stray light in the short UV region.

Hausser described a recurring erythema of human skin 12 hours after irradiation with 385 nm, and the skin became pigmented after 48 hours (8). A recurring erythema 10 to 18 hours after irradiation with wavelengths of 360, 400, 440 and 460 nm has previously been reported in healthy subjects by Pathak et al. (15). The doses used (45 J/cm²) exceeded ours and there was no account given of the stray light in their monochromator. We were not able to reproduce a late erythema in the 405 nm region.

Late pigment stimulation was seen very clearly with the 334 + 365 nm band and, in some cases, with the 365 nm band. With repeated irradiation, we were always able to stimulate late pigmentation with the 365 nm band. We could never stimulate late pigmentation with the 405 nm band (30 J/cm²) even after repeated irradiations. Our findings strengthen the observation made by Pathak et al. (15) that it is possible to stimulate late pigmentation with long-wave UV-light. In contrast to their findings, however, we were not able to stimulate pigmentation with the 405 nm band. A possible explanation for this difference might be the better short wavelength cutoff properties of our lamps.

With filters B, C and D no blister reaction occurs with a total dose of 30 J/cm² at an intensity below the EPT. The pain evoked by light of different wavelengths must be caused by the amount of radiation reaching the skin per unit of time. The IR-part of the emission from the lamps with filters B, C and D is only 8, 34 and 10% respectively of the total emission (Table II). From the results gained with the heat-filter BG 38 removed (page 269), it is evident that the addition of 300–450 mW/cm² of IR-radiation only corresponds to a lowering of the RPT by 20 mW/cm² at the 405 nm band. From this it appears that the IR radiation is of much less importance than the 405 nm band in causing pain, although it is of greater importance in the formation of blisters. This might be due to the IR radiation alone or possibly to a combined UV–IR effect. Berger (2) has given values of 600–1 000 mW/cm² as the pain threshold for his solar simulator in the long-wave UV. These values are higher than ours and, together with our results, they may indicate an interesting area-size dependence typical of pain sensation where the cooling of the skin by heat conduction and convection of intercellular fluid may be important.

ACKNOWLEDGEMENTS

This work was supported by grants from the Finsen, Jörgen Schaumann, and Edvard Welander foundations; the Swedish Psoriatic Association, the Swedish Medical Research Council (B75-19X-769-10B) and the Swedish National Research Council (K219-61, K219-63).

REFERENCES

1. Bener, P.: Spectral intensity of natural ultraviolet radiation and its dependence on various parameters. *In* The Biologic Effects of Ultraviolet Radiation (ed. F. Urbach), p. 354. Pergamon Press, 1969.
2. Berger, D. S.: Specification and design of solar ultraviolet simulators. J Invest Dermatol *53:* 192, 1969.
3. Beuttner, K. J. K.: The effects of natural sunlight on human skin. *In* The Biologic Effects of Ultraviolet Radiation (ed. F. Urbach), p. 237. Pergamon Press, 1969.
4. Freeman, R. G., Owens, D. H., Knox, J. H. & Hudson, H. T.: Relative energy requirements for an erythemal response of skin to monochromatic wave lengths of ultraviolet present in the solar spectrum. J Invest Dermatol *47:* 586, 1966.
5. Hatchard, C. G. & Parker, C. A.: A new sensitive chemical actinometer. II. Potassium ferrioxalate as a standard chemical actinometer. Proc R Soc Lond *A 235:* 518, 1956.
6. Hausser, K. W. & Vahle, W.: Die Abhängigkeit des Lichterythemes und der Pigmentbildung von der Schwingungszahl (Wellenlänge) der erregenden Strahlung. Strahlentherapie *13:* 41, 1922.
7. Hausser, K. W.: Einfluss der Wellenlänge in der Strahlenbiologie. Strahlentherapie *28:* 25, 1928.
8. Hausser, I.: Über spezifische Wirkungen des langwelligen ultravioletten Lichts auf die menschliche Haut. Strahlentherapie *62:* 315, 1938.
9. Koller, L. R.: Ultraviolet Radiation, 2nd ed, p. 169. John Wiley & Sons, New York, 1965.
10. Mackenzie, L. A. & Frain-Bell, W.: The construction and development of a grating monochromator and its application to the study of the reaction of the skin to light. Br J Dermatol *89:* 251, 1973.
11. Magnus, I. A., Porter, A. D., McCree, K. J., Moreland, J. D. & Wright, W. D.: A monochromator. An apparatus for the investigation of the responses of the skin to ultraviolet, visible and near infra-red radiation. Br J Dermatol *71:* 261, 1959.
12. Magnus, I. A.: Studies with a monochromator in the common idiopathic photodermatoses. Br J Dermatol *76:* 245, 1964.

13. Olson, R. L., Sayre, R. M. & Everett, M. A.: Effect of field size on ultraviolet minimal erythema dose. J Invest Dermatol *45:* 516, 1965.
14. — Effect of anatomic location and time on ultraviolet erythema. Arch Dermatol *93:* 211, 1966.
15. Pathak, M. A., Riley, F. C. & Fitzpatrick, T. B.: Melanogenesis in human skin following exposure to long-wave ultraviolet and visible light. J Invest Dermatol *39:* 435, 1962.
16. Rottier, P. B.: The erythematogenous action of ultraviolet light on human skin. I. Some measurements of the spectral response with continuous and intermittent light. J Clin Invest *32:* 681, 1953.
17. — *In* The Biologic Effects of Ultraviolet Radiation (ed. F. Urbach), p. 130. Pergamon Press, 1969.
18. Turnbull, B. C., Frain-Bell, W. & Mackenzie, L. A.: The development of a xenon arc lamp equipment for the assessment of photosensitivity. Br J Dermatol *79:* 369, 1967.
19. Wiskemann, A. & Wulf, K.: Untersuchungen über den auslösenden Spektralberich und die direkte Lichtpigmentierung bei chronischen und akuten Lichtausschlägen. Arch Klin Exp Derm *209:* 443, 1959.

Received January 20, 1975

L. Juhlin, M.D.
Department of Dermatology
University Hospital
S-750 14 Uppsala
Sweden