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Contents:

- 89/1 Results of a CIE Detector Response Intercomparison
- 89/2 Photobiological Effects of Sunlamps
- 89/3 On the Deterioration of Exhibited Museum Objects by
Optical Radiation
- 89/4 Guide for the Measurement of Underground Mine Lighting

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CONTENTS

	Page
Results of a CIE Detector Response Intercomparison	1
Photobiological Effects of Sunlamps	9
On the Deterioration of Exhibited Museum Objects by Optical Radiation	25
Guide for the Measurement of Underground Mine Lighting	37
Abstracts of CIE Technical Reports published in 1990	46

Results of a CIE Detector Response Intercomparison

This Technical Report was prepared by CIE TC 2-06: Absolute Spectral Responsivity of Detectors

The following is a listing of the members of CIE Technical Committee TC 2-06 on Absolute Spectral Responsivity of Detectors. An asterisk (*) identifies those members who made the detector measurements for this intercomparison.

* Armatis, Philip	U.S.A.	* Chommeloux, Beatrice	France
Christy, James	U.S.A.	* Jean, B.	France
* Duda, Richard	U.S.A.	Mercier, Brigitte	France
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* Ohno, Yoshihiro	Japan	Hengstberger, F.	South Africa
* Suyama, Keiji	Japan	Tong-Bao, Li	China

Abstract

A total of fifteen laboratories participated in the CIE detector response intercomparison which was designed to assess the level of agreement among participating laboratories in the absolute measurement (with respect to SI) of photodetector response in the visible spectral region. Most participants were either commercial laboratories or university laboratories with the National Institute of Standards and Technology (NIST) serving as the host laboratory. Each laboratory determined the absolute response of each of two silicon photodiode radiometers which were designed for the intercomparison by NIST. Approximately two-thirds of the laboratories reported response values which agreed with the NIST values to within $\pm 1.0\%$ at the two wavelengths of 488 and 633 nm.

+) Editors on behalf of TC 2-06

Copies of the full report are available at the CIE Central Bureau, Vienna and at the National Institute of Standards and Technology, Gaithersburg, Maryland, 20899, U.S.A.

Resumé

Quinze laboratoires situés tant aux Etats-Unis que dans d'autres pays du monde entier ont pris part, dans le cadre de la CIE, à une comparaison de mesures de sensibilité de détecteurs qui avait pour but de déterminer le niveau d'accord existant entre les laboratoires participants, pour la mesure de la sensibilité absolue (par rapport au SI) des photodétecteurs dans le domaine visible. La plupart des participants étaient des laboratoires industriels ou des laboratoires universitaires. Le National Institute of Standards and Technology (NIST) jouait le rôle de laboratoire pilote. Chaque laboratoire a déterminé la sensibilité absolue de deux radiomètres équipés de photodiodes au silicium, et spécialement réalisés pour cette comparaison par le NIST. Les résultats fournis par environ les 2/3 des laboratoires sont en accord avec ceux du NIST dans la limite d'incertitude de $\pm 1\%$ pour les longueurs d'onde de 488 et 633 nm.

Zusammenfassung

Insgesamt fünfzehn Laboratorien haben an CIE-Vergleichsmessungen von optischen Strahlungsempfängern teilgenommen. Der Vergleich bezweckte, die Übereinstimmung unter den teilnehmenden Laboratorien in der Absolutmessung (relativ zu SI-Einheiten) der Empfindlichkeit von Halbleiter-Empfängern im sichtbaren Spektralgebiet zu bestimmen. Die Mehrzahl der Teilnehmer waren Industrie- oder Universitätslaboratorien. Das U.S. National Institute of Standards and Technology (NIST) war das Zentrallaboratorium. Jedes Labor bestimmte die absolute Empfindlichkeit von je zwei speziell für diesen Vergleich entwickelten NIST-Radiometern mit Silizium-Photodioden. Etwa zwei Drittel der von den einzelnen Laboratorien gemessenen Empfindlichkeiten lagen innerhalb $\pm 1\%$ der NIST-Werte bei 488 und 633 nm.

1. Introduction

This report provides the final results of a detector response intercomparison under the aegis of CIE Technical Committee TC 2-06 on Absolute Spectral Responsivity of Detectors.

The primary purpose of the intercomparison was to assess the level of agreement among participating laboratories in the absolute measurement (with respect to SI) of photodetector response (A/W) in the visible spectral region. The method chosen to accomplish this is to have these laboratories measure the absolute response of selected radiometers at two specific wavelengths near each end of the visible spectrum. The wavelengths selected are those of the helium-neon laser (632.8 nm) and the argon ion laser (488.0 nm).

The intercomparison was implemented on the basis of the National Institute of Standards and Technology (NIST) serving as the host laboratory and providing (a) the radiometers to be used in the intercomparison, (b) instructions to participating laboratories in the use of the radiometers in absolute response measurements, and (c) data analysis and a report of the results of the intercomparison.

The intercomparison was conducted in two stages: (1) intercomparison of U.S. laboratories and (2) intercomparison of laboratories outside of the United States. All participating laboratories except two are either commercial laboratories or university laboratories. The Electrotechnical Laboratory in Ibaraki, Japan and the Van Swinden Laboratory, The Netherlands, are national standards laboratories. The intercomparison was planned on the basis that NIST would measure the absolute response of all radiometers before shipment to the participating laboratories and then again after the radiometers were returned. The NIST absolute response value for each radiometer would be the average of the NIST measurements.

2. The Radiometers

The radiometers used in this intercomparison were designed for ruggedness and ease of use and included commercially available silicon photodiodes. Each radiometer consists of a silicon photodiode and amplifier circuit mounted in a cylindrical aluminum housing and an external power supply.

Since it was expected that the majority of the laboratories would make their measurements using lasers, the photodiodes were not protected by a window. However, to protect each photodiode during non-use, the diodes were maintained in sealed compartments.

Two types of detectors were used: EG&G model UV-444B PN photodiodes and UDT model UV-100 inversion layer photodiodes. For the UDT photodiodes, a constant reverse bias voltage (4.5 V) was supplied by lithium batteries within each radiometer. The amplifier in each radiometer has gain settings from 10^4 to 10^9 V/A with accuracies of ± 0.03 % except for the 10^9 range where it is ± 0.5 %.

3. The Intercomparison

A total of six U.S. laboratories and nine laboratories in other countries participated in the intercomparison. Each laboratory was asked to complete a questionnaire concerning detailed information about their detector response measurement system and to use standard data forms for reporting their results. Tables 1 and 2 list the laboratories and the information each submitted about their measurements at 488 and 633 nm. The information submitted covered eight measurement parameters: (1) absolute base (absolute standard(s) used), (2) standard deviation of the measurements, (3) number of measurements per radiometer, (4) type of radiation source used, (5) beam diameter of the source, (6) radiant power level at the radiometer, (7) ambient temperature during measurements, and (8) estimated uncertainty (with respect to SI) of the absolute standards used. Some laboratories used a single silicon photodiode as an absolute (standard) base for their measurements. The absolute response of these photodiodes was determined using the self-calibration method [1,2]. Two laboratories made measurements only at 633 nm. Of the fifteen laboratories participating in the intercomparison, five laboratories used lasers as radiation sources at both wavelengths and five used a tungsten lamp/filter/monochromator system at both wavelengths. The remaining laboratories used various combinations of these sources. Radiant power levels ranged from 0.16 μ W to 0.7 mW.

The measurement system used at NIST for this intercomparison consists of He-Ne and Argon ion lasers, laser stabilizer, spatial filter, beam splitter and a silicon photodiode monitor detector. Three UDT QED-200 absolute radiometers [3] were used as base standards. The NIST procedures for determining the absolute response of the intercomparison radiometers consisted basically of two steps: (1) measuring the ratio of the photocurrent of each UDT QED-200 radiometer to the photocurrent of the monitor detector at a particular laser power setting and (2) measuring the ratio of the photocurrent of the intercomparison radiometers to the monitor detector at the same power level in (1). Since the UDT QED-200 radiometers are 100 % quantum efficient (with voltage bias) at the wavelengths and power levels stated, the power (watts) can be accurately measured and the absolute response (amperes/watt) of each of the intercomparison radiometers can be determined. Details concerning the system and the measurement procedure are further described in [4]. The NIST absolute base was compared to other international standards laboratories in a recent detector response intercomparison sponsored by the Consultative Committee on Photometry and Radiometry (CCPR) [5]. In the CCPR intercomparison, the absolute response of a select group of silicon photodiode radiometers were measured by 10 international standards laboratories and also by NIST which served as the host laboratory. The ratios of the NIST response values to the mean of the response values of the other participating laboratories were 1.0011 ± 0.0035 and 1.0014 ± 0.0037 at the two wavelengths of 488 and 633 nm, respectively.

Since the absolute response values reported by each of the participating laboratories were compared to the response values determined at NIST, it was essential for NIST to measure the

TABLE 1: WAVELENGTH = 488 nm
LABORATORY

	ABSOLUTE BASE	S.D. OF MEASURE.	NO. OF MEAS. /RADIOMETER	RADIATION SOURCE	BEAM DIAM.	POWER LEVEL	AMBIENT TEMP. (C)	ABSOLUTE UNCERTAINTY
Lawrence Livermore Nat. Lab. Livermore, California, USA	EG&G UV-444-BQ Photodiode	0.24- 0.35%	5	Tung./Filter	Aperture Overfill	3.7×10^{-8} W/cm ²	22	0.77%
National Inst. of Standards &Tech., Gaithersburg, Maryland, USA (Host Lab)	UDT QED-200 Radiometer	0.01%	50	Ar Ion Laser	4mm	0.5mW	25-26	0.10%
Tektronix Corporation Beaverton, Oregon, USA	UDT QED 100 Radiometer UDT UV 100L Photodiode	0.11%	3	Tung./Mono chromator	2.5x5.0mm Rectangle	0.6μW	23	0.17%
United Detector Technology Hawthorne, California, USA	UDT QED 200 Radiometer	0.039- 1.10%	2	Bentham M300 Monochromator	1 x 5mm Rectangle	2.0μW	21	0.07%
University of Arizona, Tucson, Arizona, USA	UDT QED 200 Radiometer	0.003- 0.018%	48	Tung./Filter	2.5x3.5mm Rectangle	4.0μW	21	0.05%
Westinghouse Electric Corp. Baltimore, Maryland, USA	---	---	---	---	---	---	---	---
Central Inst. of Physics, Magurele, Bucharest, ROM	PN Silicon Photodiode	0.17- 0.21%	10	Ar. Ion Laser	4mm	0.02mW	18	0.17%
Electrotechnical Laboratory Ibaraki, JPN	Hamamatsu S 1337 Photodiode	0.04%	4	Tung./Mono- chromator	2 x 3mm Rectangle	0.16μW	23	0.07%
Hamamatsu Photonics K.K., Hamamatsu City, JPN	---	---	---	---	---	---	---	---
L.C.I.E., Fontenay-Aux-Roses, FRA	Silicon Photodiode	0.6%	6	Tung./Mono chromator	5mm	20μW	23	0.20%
Laboratoire National D'Essais, Paris, FRA	Three Silicon Photodiodes	0.11- 0.18%	27, 33	Tung./Mono- chromator	6mm	1.5μW	23	0.11 0.22%
Matsushita Elect.Indust.Co. Ltd, Moriguchi Osaka, JPN	Hamamatsu S 1337 Photodiode	0.02%	10	Ar Ion Laser	3mm	0.19mW	25	0.07%
PRC Krochmann GmbH, Berlin, EU	Hamamatsu S 1227 Photodiode	0.52%	5	Tung./Mono- chromator	7mm	2.4×10^{-3} W/m ²	23	0.17%
University College, Dublin, IRL	EG&G UV-444B Photodiode	0.12- 0.04%	8-12	Ar Ion Laser	0.6mm	0.3mW	21	0.50%
Van Swinden Laboratory, Delft, NDL	UDT QED-200 Radiometer	0.007- 0.011%	75	Ar Ion Laser	4mm	0.7mm	23	0.20%

TABLE 2: WAVELENGTH = 633 nm
LABORATORY

LABORATORY	ABSOLUTE BASE	S.D. OF MEASURE.	NO. OF MEAS. /RADIOMETER	RADIATION SOURCE	BEAM DIAM.	POWER LEVEL	AMBIENT TEMP. (C)	ABSOLUTE UNCERTAINTY
Lawrence Livermore Nat. Lab. Livermore, California, USA	EG&G UV-444-BQ Photodiode	0.28%	5	Tung./Filter	Aperture Overfill	4.9×10^{-8} W/cm ²	22	0.77%
National Inst. of Standards &Tech., Gaithersburg, Maryland, USA (Host Lab)	UDT QED-200 Radiometer	0.012%	50	He/Ne Laser	4mm	0.5mW	25-26	0.10%
Tektronix Corporation Beaverton, Oregon, USA	UDT QED 100 Radiometer	0.015- 0.12%	6	Tung./Mono- chromator	2.5x5.0mm Rectangle	0.6µW	23	0.17%
	UDT UV 100L Photodiode			He/Ne Laser	2.5mm	0.5mW		
United Detector Technology Hawthorne, California, USA	UDT QED 200 Radiometer	0.3 - 0.4%	2	Bentham M300 Monochromator	1x5mm Rectangle	2.0 µW	21	0.07%
				He/Ne Laser	4mm	0.5mW		
University of Arizona, Tucson, Arizona, USA	UDT QED 200 Radiometer	0.018- 0.004%	64	Tung./Filter	2.5x3.5mm Rectangle	11µW	21	0.05%
Westinghouse Electric Corp. Baltimore, Maryland, USA	UDT UV 100L Photodiode, UDT QED 200 EG&G UV-444-BQ	0.26- 0.14%	3	He/Ne Laser	2mm	0.44mW	20.8	0.05%
Central Inst. of Physics, Magurele, Bucharest, ROM	PN Silicon Photodiode	0.17- 0.14%	10	He/Ne Laser	4mm	0.1mW	18	0.17%
Electrotechnical Laboratory Ibaraki, JPN	Hamamatsu S 1723 Photodiode	0.02%	3	He/Ne Laser	1mm	0.4µW	23	0.07%
Hamamatsu Photonics K.K., Hamamatsu City, JPN	Hamamatsu S 1337 Photodiode	0.07- 0.04%	10	He/Ne Laser	1.5mm	25µW	25	0.17%
L.C.I.E., Fontenay-Aux-Roses, FRA	Silicon Photodiode	0.6%	6	Tung./Mono- chromator	5mm	30µW	23	0.20%
Laboratoire National D'Essais, Paris, FRA	Three Silicon Photodiodes	0.10- 0.08%	21, 28	Tung./Mono- chromator	6mm	2µW	23	0.12- 0.09%
Matsushita Elect.Indust.Co. Ltd, Moriguchi Osaka, JPN	Hamamatsu S 1337 Photodiode	0.02%	10	He/Ne Laser	3mm	0.3mW	25	0.07%
PRC Krochmann GmbH, Berlin, DEU	Hamamatsu S 1227 Photodiode	0.3- 0.15%	5	Tung./Mono- chromator	7mm	1.1×10^{-2} W/m ²	23	0.17%
University College, Dublin, IRL	EG&G UV-444B Photodiode	0.07- 0.08%	6	He/Ne Laser	0.6mm	0.6mW	18	0.08%
Van Swinden Laboratory, Delft, NDL	UDT QED-200 Radiometer	0.02%	75	He/Ne Laser	4mm	0.7mW	23	0.20%

Since the absolute response values reported by each of the participating laboratories were compared to the response values determined at NIST, it was essential for NIST to measure the response of each set of radiometers *before* it was shipped to the participating laboratory and then measured again *after* the radiometers were returned. The *before* and *after* measurements by NIST were made to determine if any significant changes occurred in the radiometers during shipment.

4. Data Analysis

Since three of the four radiometers with the EG&G type photodiode showed small but significant decreases in response at 488 nm over a 7-month period, it was decided to use only the radiometers with the UV-100 type photodiodes for the second phase of the intercomparison (foreign laboratories).

Figures 1 and 2 are plots of the ratios of the response values (A/W) determined by each of the participating laboratories to the respective response values (A/W) determined by NIST at 488 and 633 nm. The solid line on each plot is the mean of all the ratios at the respective wavelength and the dashed lines are the standard deviation of the mean.

The absolute response ratio uncertainty, the quadrature summation of the measurement and absolute uncertainties of each participant laboratory, the *before/after* response change for each radiometer and the NIST measurement and absolute uncertainties has been calculated as well. The error bars in figures 1 and 2 indicate the absolute response ratio uncertainty for each laboratory.

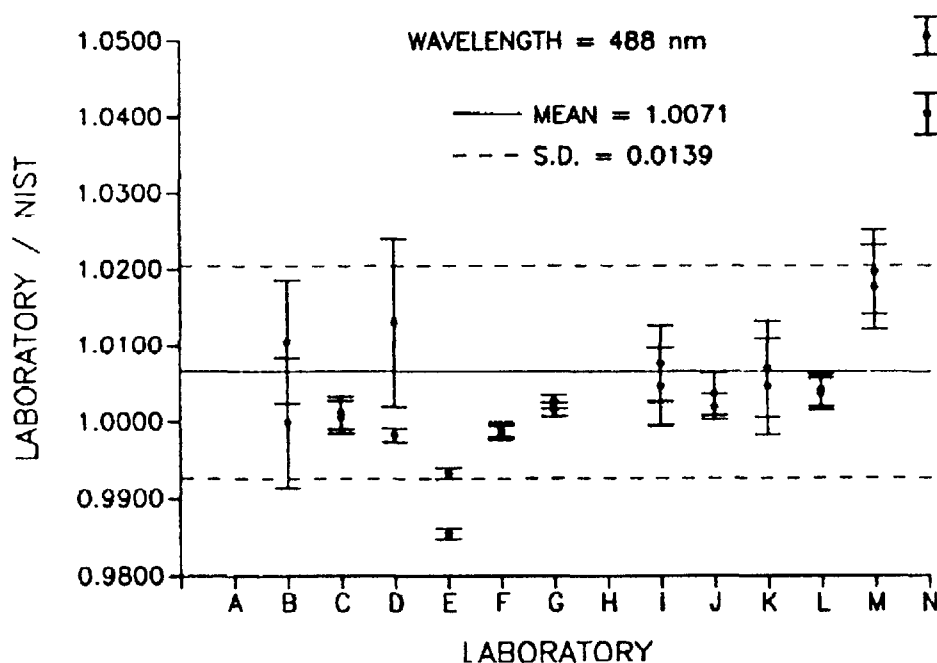


Fig. 1:

Ratio of the participant laboratory spectral response to that determined by NIST. The error bars indicate the quadrature summation of the measurement and absolute uncertainties of each participant laboratory, the *before/after* response change for each radiometer and the NIST measurement and absolute uncertainties. The dashed lines indicate the standard deviations of the ratio values.

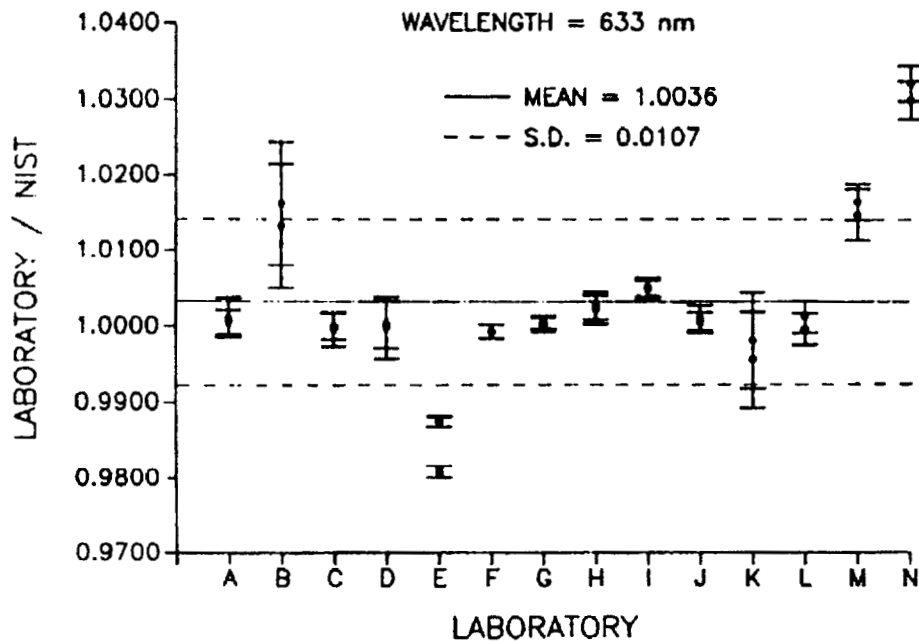


Fig. 2:
For figure caption see Fig. 1.

5. Conclusion

In general, it can be concluded that most of the response values reported by the laboratories were in good agreement with NIST. At 488 nm, the mean of all participating laboratories was 0.71 % higher than the corresponding NIST values with a standard deviation of 1.39 %. Similarly, at 633 nm, the mean of all laboratory values was higher than the NIST values by 0.36 % with a standard deviation of 1.07 %. All laboratories participating in this intercomparison (except laboratory N) reported values at both wavelengths within ± 2.0 % of the NIST values and nine of the 14 laboratories reported values at both wavelengths within ± 1.0 % of the NIST values. This can be considered good agreement among the laboratories when one considers the variety of sources, procedures and testing environments involved in this intercomparison.

6. References

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- [3] Zalewski, E. F., and Duda, C. Richard, *Appl. Opt.* **22**, 2867 (1983).
- [4] Thomas, D. B., and Zalewski, E. F., A Radiometer For Precision Coherent Radiation Measurements, SPIE Tech. Symp. on Aerospace Sensing, Orlando, Florida, March 1989.
- [5] Annual Report of the Consultative Committee on Photometry and Radiometry, International Bureau of Weights and Measures, Sèvres Cedex, France (1986).

Division 6 Report

Photobiological Effects of Sunlamps *

Report by B. Muel

Abstract:

The different types of sunlamps now in use are reviewed and their spectral irradiances compared. The short and long term risks of the use of such devices are discussed according to the type of radiation, the skin types and the conditions of use. A short review of the existing or proposed regulations or recommendations of Official Committees is presented.

Résumé:

Les différents types de lampes à bronzer en usage actuellement sont passés en revue et les éclairagements spectraux sont comparés. Les risques à court terme et à long terme liés à l'utilisation de ces lampes sont discutés en tenant compte du type de rayonnement, du type de peau des individus et des conditions d'emploi. Enfin, nous présentons une courte revue des réglementations existantes ou proposées et des avis donnés par des Comités Officiels.

Zusammenfassung:

Die verschiedenen gebräuchlichen Bräunungslampentypen werden untersucht, ihre spektrale Strahlung wird verglichen. Die kurz- und langfristigen Gefahren beim Einsatz dieser Geräte werden nach Strahlungsart, Hauttyp und Einsatzbedingungen behandelt. Es wird ein kurzer Überblick über die gegenwärtigen Regelungsvorschläge oder -empfehlungen offizieller Komitees gegeben.

1. Introduction

Among the white population, the fashion of having a tanned skin appeared in the twenties of this century and since then it became more and more widespread up to the present time. Recently this tendency may have been reduced by repeated warnings from dermatologists not to abuse sun exposure as it became obvious that skin aging and incidence of most of the skin cancers were increased by this behaviour.

Sunlamps are used to complement solar radiation exposures to obtain a tan. It is obvious that such a use might have the same short and long term drawbacks as solar radiation exposures. The Health and Welfare Administration of Canada (1981) noted that 2000 people are treated every year for sunlamp burns and eye damage. The heating effect of such lamps might also be a problem.

* Definition:

In this report "sunlamp" refers to any ultraviolet irradiation device intended for non-medical use, the aim being usually to achieve tanning of the skin for cosmetic purposes.

2. Spectral irradiances at skin level from sunlamps

Figure 1 illustrates the irradiance spectra of five sunlamps, typical of those used in Europe (Muel 1987a). They are compared with an average summer sun spectrum in Europe (zenith angle 40°).

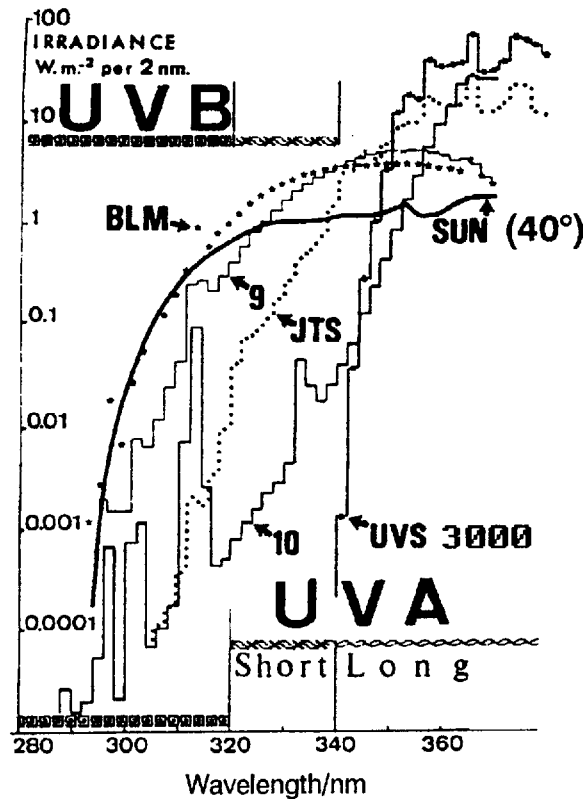


Fig. 1: Typical sunlamps and solar irradiance spectra.
See Table 1 for an explanation of symbols.

Table 1 lists the absolute radiometric irradiances in the UVA and erythral irradiances in UVA, UVB and their ratios. Results for 2 sunlamps whose spectra are not shown in Fig. 1 are included. The erythral irradiances are calculated according to an interpolation of the action spectrum for sensitive skin types (skin types I and II, as defined in 3.3.2), average of 8 and 24 h erythema (Parrish 1982).

The spectra of sunlamps which have been introduced in recent years show a shift towards the longer wavelengths. This is clear from the data of Table 1 where the lamps are ordered according to their approximate date of appearance on the market. The ratios of UVB to the total erythral irradiances fell from more than 99 % to less than 0.04 %, whilst irradiances in UVA have increased by 60 times. For UVS 3000 the UVA irradiance is 15 times the sun irradiance for a zenith angle of 20°.

Table 1: Energetic and erythema l irradiances, ratios and times

Designation*	Irradiances W.m ⁻²				Times for one MED 300 J.m ⁻²
	Radiometric	E r y t h e m a l			
	UVA	UVA	UVB	Ratios	
	(320-400nm)	(320-410nm)	(280-320nm)	UVB/Total	
SUN (40°)	56	0.032	0.202	0.86	21 min 20 s
SUN (20°)	68	0.043	0.400	0.90	11 min 20s
HG	17	0.009	2.15	0.996	2 min 20 s
BLM	98	0.069	0.206	0.75	18 min
9	100	0.063	0.037	0.37	50 min
10	240	0.070	0.005	0.065	67 min
JTS	443	0.126	5 x10 ⁻⁴	4 x10 ⁻³	40 min
UVS 2000	720	0.190	< 10 ⁻⁴	< 5x10 ⁻⁴	26 min
UVS 3000	1044	0.247	< 10 ⁻⁴	< 4x10 ⁻⁴	20 min

*SUN(40°) = Sun, zenith angle 40°, latitude of Brittany in France, 4 PM local time (2 PM solar time), June 21st,
SUN(20°) = zenith angle 20°, French Riviera June 21st (noon solar time),
HG = 300 W mercury arc in glass envelope at 50 cm, from data given by the manufacturer,
BLM, 9, 10 = Sun-beds with fluorescent tubes,
JTS, UVS 2000 = 2000 W mercury-metal-halide arc + filters, measurement centred at 20 cm from the filters,
UVS 3000 = 3000 W mercury-metal-halide arc + filters, at 20 cm.

3. Skin effects

3.1 Action spectra

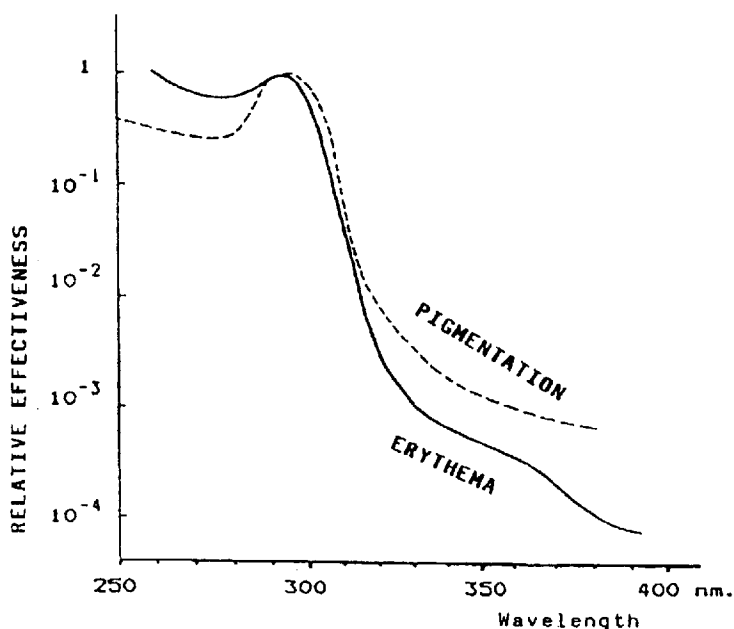


Figure 2: Action spectra for erythema and pigmentation in caucasian skin.

Figure 2 illustrates the action spectra for pigmentation and erythema for caucasian skin. These spectra differ for sensitive skintypes I -II (Parrish 1982), and for resistant types III-IV (Gange 1986).

A simple (straight lines in semi-log graph) reference erythema action spectrum was proposed in the TC 6-02 of the CIE by averaging all results from the literature up to 1987 (McKinlay 1987). Similar action spectra are being proposed in the TC 6-10 of the CIE (Mutzhas 1990a) for erythema in resistant skin types and for tanning in both sensitive and resistant cases.

Fig. 2 is based on the average spectra of Parrish (1982) (sensitive) and Gange (1986) (resistant), the erythema being observed at 8 hours and the pigmentation at 7 - 14 days after irradiation. These spectra indicate that, for equal erythema effects in the UVA and in the UVB, there is about 3 times more pigmentation effect in UVA than in UVB. This means that for a given pigmentation effect UVA leads to less erythema than UVB. Moreover, it was evaluated (Van Weelden 1986) that the carcinogenic effect in mice is about three times less for UVA than for UVB for equal acute reaction (oedema). Then, UVA may be about 9 times less carcinogenic than UVB for equal tanning doses. These considerations are the basis for the justification for using only UVA for tanning.

This position has been criticized by a panel of photobiologists (Roza 1989). According to the authors, the action spectra for tanning in man and of photocarcinogenesis in mice recently obtained in Van der Leun's group (Slaper 1987a) (Figure 3) are not significantly different. This would indicate that there is little or no difference in carcinogenic risk of tanning in UVA or in UVB. It should be pointed out that in the spectra presented in Figure 3 the results for pigmentation are those of Parrish (1982) for sensitive I and II skin types and it is not taken into account that the melanogenesis action spectrum for resistant skin-types III and IV is higher in the UVA. This approach can be justified by the fact that people with dark skin have a small risk of skin cancer, whatever their behavior, so that the population at risk is the sensitive one and it is the one to be considered in this discussion.

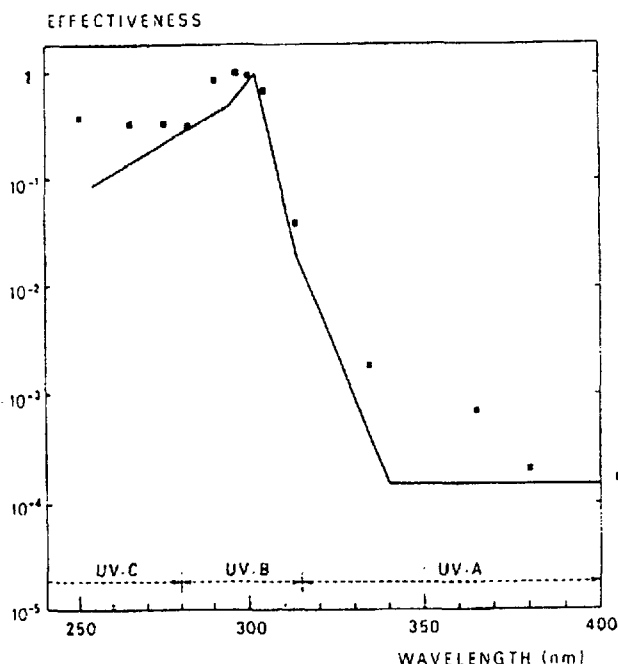


Figure 3: Action spectrum for UV carcinogenesis in mouse skin (line) and action spectrum for pigmentation of sensitive human skin (points) (from Roza 1989).

An experiment with mice (Kaase 1984) seemed to show that the carcinogenicity of the long wavelengths UVA containing no measurable UV below 340 nm (same spectrum as UVS 3000 in Fig. 1) was negligible. The carcinogenicity of long wavelengths UVA (van Weelden 1983, van Weelden 1986, Sterenborg 1987, Sterenborg 1990) containing a very low but measurable proportion of UV between 320 and 340 nm (Mutzhas 1981) might possibly be due to the small content of short UVA. In favour of such an interpretation is the recent preliminary report (Mutzhas 1990b) which shows that irradiation by UVA strictly above 340 nm, did not induce immunosuppressive effects in humans as other UV wavelengths do. Nevertheless, another preliminary report (Kligman 1990) shows that tumours do appear in mice irradiated by radiations above 340 nm and containing no measurable UV below 340 nm, with repeated doses of the order of magnitude of doses used for a tanning session. The conflicting results by Kaase and by Kligman may just possibly come from a higher proportion of infrared in Kligman's experiment (Mutzhas 1990c). This has to be verified.

Concerning the effect of irradiance on the carcinogenicity of UV exposures, some experiments (Forbes 1977) showed a somewhat reduced carcinogenic effect of high irradiances (for equal doses), but a preliminary communication (Menter 1990) showed the reverse effect, or no effect, depending on the spectrum of the radiation used. Anyway these effects are small.

In conclusion, it may be said that although UVA tanning is less erythema and possibly less carcinogenic than UVB tanning in resistant skin types, it is probably less so for sensitive skin types.

Moreover a reduction of carcinogenic risk by using UVA above 340 nm or high irradiances remains conjectural.

Concerning the aging of skin, which is not a small risk but which is almost bound to occur by repeated overexposure to UV radiation, action spectra were obtained with mice (Bisset 1989, Wulf 1989). The result is that UVA is much more active than UVB in skin damaging for equivalent erythematous doses. For elastosis, Kligman (1991) arrived at the opposite conclusion by a different technique.

Concerning protection against solar radiation offered by tanning, UVB can produce a protection factor of up to 10 and UVA up to 3 (Kaldbey 1986). This might help people who want to go on vacation with some skin protection so that they can stay in the sun with less initial concern. UVB is better for this purpose.

3.2 Estimation of carcinogenic risk from artificial tanning

3.2.1 Models

Calculations for predicting carcinogenic risk can be done under two fundamental hypotheses:

- hypothesis no. 1: The relation observed for homogeneous populations between latitude and the incidence of skin cancers is due mainly to the change of erythematous or carcinogenic annual dose (that is a dose weighted by the efficacy of erythema or cancer formation in mice, at each wavelength). The action spectra are close to each other and it does not matter whether erythema or carcinogenicity is the endpoint.
- hypothesis no. 2: for each additional exposure, one must assume a mathematical relation between the increase of incidence of skin cancers and the additional weighted dose, consistent with the epidemiological results, according to hypothesis no. 1.

Table 2 gives some examples of such calculations for the risk of epithelioma from artificial tanning.

Table 2: Risk of epithelioma from artificial tanning

	Annual Number of tanning sessions	Increase of epithelioma in life time
Césarini-Muel (Simple Model)	60	20 %
Diffey (Intermediate)	50	30 %
Slaper (Complex Model)	60	40 %

From animal studies, the incidence of epithelioma varies as approximately the square of the annual dose (Van der Leun 1984). This emphasizes the effect of small additional doses. In the Césarini-Muel model (Césarini 1983), the relation with annual dose is simply deduced from the epidemiological results (Fears 1976, Scotto 1982) of incidence as a function of latitude, knowing the relation between latitude and annual erythematous dose (Berger 1982) and knowing from photosensitive badge dosimeter studies that humans receive about 1/10th of the available UV (Larkö 1983, Diffey 1984). Diffey (1987a) and Slaper (1987b) used mathematical relations between dose and cancer production, obtained in mice studies. The Slaper model is the most sophisticated model, taking into account the variation of dose during lifetime and the parts of the body exposed.

It must be stressed that such calculations provide only an order of magnitude assessment of the risk, resting on the validity of several probable but unproven assumptions.

For malignant melanoma, although the relation with latitude is very clear (Fears 1976, Scotto 1982), the effect of radiation seems to depend very much on tanning of the skin, the age at exposure and the skin damage after each exposure (Holman 1986). Moreover, no action spectrum is known so that calculations based on cumulative erythema dose during life are very uncertain. As for skin epithelioma, any increase of UV radiation dose is liable to increase the risk of malignant melanoma.

3.2.2 Epidemiology

a) Squamous cell carcinoma

A small case-control (92 cases) study (Aubry 1985) showed surprisingly a very strong correlation with a relative risk for squamous cell carcinoma of 13.4 for sunlamp users with respect to non-users. The authors used logistic regression analysis so that other variables such as sunlight exposure seem to have been taken into account and the relation should not be attributed to the fact that sunlamp users are usually also sun worshippers. The type of sunlamps used were described only as "long tube type" with no details concerning their spectral properties.

b) Malignant melanoma

A few isolated cases of melanoma in sunlamp users were mentioned (Brodthagen 1981, Retsas 1983), in particular, a melanoma appearing at the place normally covered by a watch and only irradiated during the sunlamp sessions (Brodthagen). Of more concern are three case-control studies which show an association of malignant melanoma with sunlamp use.

The first association was found in an English study designed to test the effect of oral contraceptives (Adam 1981). There was a significantly higher rate of women having used sunlamps in patients with melanoma than in the general population.

The second study in Scotland (Swerdlow 1988) covering 180 cases shows a significant linear trend of increase with time of use, with a relative risk of 3.4 for more than one year of use, after adjustment for the effects of several other risk factors including exposure to sun.

The third made in Canada (Walter 1990) covered 583 cases. There is a significant trend of increase with time of use, with a relative risk above 2 for more than one year of use. Adjustments were made for the effects of several other risk factors, but unfortunately not for solar exposures. The association is statistically significant when home use is considered, but not for use in commercial salons.

3.2.3 Conclusions

The epidemiological studies are sufficiently positive to urge for verification by other similar studies. It would be very important to distinguish between types of lamps (proportion of UVB), because if a difference exists, it might give an indication on the relative efficiencies of UVA and UVB for carcinogenesis in man. This would be particularly interesting in the case of malignant melanoma for which no such data are available even in animals. In such studies, the possible confounding effect of probably higher solar exposures in sunlamp users would have to be carefully examined.

From the practical point of view, the epidemiological results together with the theoretical predictions indicate that the carcinogenic risk of using sunlamps has to be taken very seriously and that excessive use should be strongly discouraged just as it is for exposures to sun radiation.