Physical characteristics and sources of exposure to artificial UV radiation

For most individuals, the main source of exposure to ultraviolet (UV) radiation is the sun. Nevertheless, some individuals are exposed to high doses of UV through artificial sources. Sunbeds and sunlamps used for tanning purposes are the main source of deliberate exposure to artificial UV radiation.

Physical characteristics of UV radiation

UV radiation belongs to the non-ionizing part of the electromagnetic spectrum and ranges between 100 nm and 400 nm; 100 nm has been chosen arbitrarily as the boundary between non-ionizing and ionizing radiation. UV radiation is conventionally categorized into 3 regions: UVA (>315–400 nm), UVB (>280–315 nm) and UVC (>100–280 nm) (Figure 1).

These categories have been confirmed by the Commission Internationale de l'Eclairage (CIE, 1987), although there is variation in usage. In the medical and biological fields, for example, 320 nm is used as the limit between UVA and UVB. More recently, it was proposed to distinguish between UVA-1 (>340–400 nm) and UVA-2 (320–340 nm).

Units and measurements of UV radiation

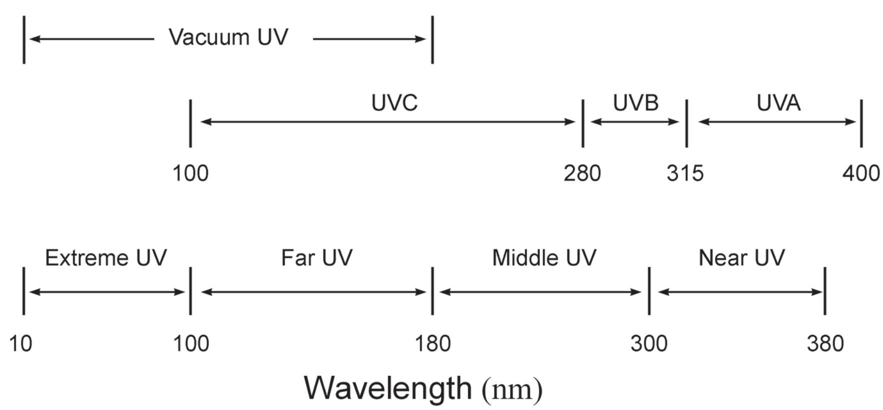
Measurement of ambient solar UV radiation

Measurement of ambient solar UV radiation has been performed worldwide for many years. However, UV radiation detectors for research or individual use have been developed only recently. There are two principal types of instruments: steady spectroradiometers, which screen the entirety of the UV spectrum (100–400 nm) within a few minutes, and broad-spectrum dosimeters, which can measure solar irradiance within a few seconds. Individual dosimeters, which can easily be placed at strategic places on individuals, are of the second type.

Broad-spectrum instruments often include a weighting factor representative of a given biological spectrum (e.g. skin erythema). In current practice, the margin of error for the measurement is relatively high, around 30%.

The biologically relevant UV radiation dose at a given wavelength corresponds to the measured UV radiation multiplied by a weighting factor specific to the biological endpoint considered (e.g. erythema, pigmentation, carcinogenesis, etc.) at that wavelength. For the overall dose (Eeff

Figure 1. Ultraviolet (UV) region of the electromagnetic spectrum



Adapted from IARC (1992)

Table 1. Specifications of relative erythemal effectiveness

Wavelength (λ; nm)	**Relative erythemal effectiveness (Sλ) (weighting factor)**
$\lambda < 298$	1
$298 < \lambda < 328$	$10^{0.094(298-\lambda)}$
$328 < \lambda \leq 400$	$10^{0.015(139-\lambda)}$

From McKinlay & Diffey (1987); International Electrotechnical Commission (1989)

expressed in watts per square meter ($W.m^{-2}$)), the weighted components are added for all the wavelengths included in the interval considered.

The specifications of the relative erythemal effectiveness are defined by the parameters described in Table 1.

Standard erythemal dose (SED) and minimal erythemal dose (MED)

The standard erythemal dose (SED) is a measure of UV radiation equivalent to an efficient erythemal exposure of 100 joules per square meter ($J.m^{-2}$).

The clinically observed minimal erythemal dose (MED) is defined as the minimal amount of energy required to produce a qualifying erythemal response, usually after 24h. The erythemal responses that qualify can be either just-perceptible reddening or uniform redness with clearly demarcated borders, depending on the criterion adopted by the observer.

Since 1997, the Erythemal Efficacy Spectrum of human skin has become an International Organization for Standardization/International Commission on Illumination (ISO/CIE) standard that allows, by integration with the emission spectrum of any UV source, calculation of the erythemal output of this source.

UV index

The UV index is a tool designed for communication with the general public. It is the result of a common effort between the World Health Organization (WHO), the United Nations Environment Programme (UNEP), the World Meteorological Organization and the International Commission on Non-Ionising Radiation Protection (ICNIRP), and is standardized by ISO/CIE. The UV index expresses the erythemal power of the sun: UV index = 40 x E_{eff} $W.m^{-2}$ (Table 2).

Limit values

The American Conference of Governmental Industrial Hygienists (ACGIH) and ICNIRP have determined the maximal daily dose that a worker exposed to UV would be able to receive without acute or long-term effects on the eyes. This dose has been established at 30 $J.m^{-2}$ (eff), which corresponds to a little less than 1/3 of SED. The value takes into account an average DNA repair capacity in the cells.

There are currently no recommendations for safe doses for human skin.

Sources of natural and artificial UV radiation

Solar radiation

The sun is the main source of exposure to UV for most individuals. Sunlight consists of visible light (400–700 nm), infrared radiation (>700 nm) and UV radiation. The quality (spectrum) and quantity (intensity) of sunlight are modified during its passage through the atmosphere. The stratosphere stops almost all UV radiation <290 nm (UVC) as well as a large proportion of UVB (70–90%). Therefore, at ground level, UV radiation represents about 5% of solar energy, and the radiation spectrum is between 290 and 400 nm.

An individual's level of exposure to UV varies with latitude, altitude, time of year, time of day, clouding of the sky and other atmospheric components such as air pollution.

Artificial UV radiation

Artificial sources of UV radiation emit a spectrum of wavelengths specific to each source. Sources of artificial UV radiation include various lamps used in medicine, industry, business and research, and for domestic and cosmetic purposes.

Table 2. UV index and Standard Erythemal Dose[1]

UV index	Number of SED/hour	Power of the sun	Duration of exposure equivalent to 1 SED
1	1	Weak	2h20
2	2	Weak	1h10
3	2.5	Medium	45 mn
4	3.5	Medium	35 mn
5	4.15	Strong	30 mn
6	5	Strong	25 mn
7	6	Very strong	20 mn
8	7	Very strong	18 mn
9	8.5	Extreme	16 mn
10	9.5	Extreme	14 mn
11	10.5	Extreme	12 mn

[1] Exposure to 2 SED triggers a light but visible erythema in an unacclimatised sensitive individual (phototype I).

(a) UV sources used for tanning: The device used for tanning may be referred to as sunbed, sunlamp, artificial UV, artificial light or tanning bed, among other terms. Also, a number of terms are used to define a place where indoor tanning may occur: solarium, tanning salon, tanning parlour, tanning booth, indoor tanning salon, indoor tanning facility. In addition, indoor tanning may take place in private, non-commercial premises. For the purpose of this report, the term "indoor tanning facility" has been used throughout.

From the 1940s until the 1960s, exposure to UV radiation emitted by mercury lamps was popular in Northern Europe and North America. Typically, these were portable devices equipped with a single mercury lamp, sometimes accompanied by infrared lamps to heat the skin. The UV spectrum of mercury lamps consisted of about 20% UVC and 30–50% UVB radiation (Diffey *et al.,* 1990). Sometimes, ordinary glass covered the mercury lamps, limiting emission of UVB and UVC to a certain extent depending on the thickness of the glass. Exposure of individuals to these lamps was of short duration but could lead to the development of erythema, burns and blistering. These lamps were used primarily for children, to help synthesis of vitamin D, although adults may have used them to tan. These lamps were banned in most countries around 1980.

Fluorescent tubes emitting UV radiation and designed for general public use for tanning purposes were produced commercially in the 1960s. The first-generation tubes were of small size. UV units generally comprised three to six short fluorescent lamps, and tanning of the whole body was tedious, as it required exposing one body part after another. Before regulations were enforced, UVB could represent up to 5% of the UV output of these tanning devices.

In the 1980s and 1990s, amid growing concern about the carcinogenic potential of UVB, the UV output of low-pressure fluorescent lamps was shifted towards UVA, allowing so-called "UVA tanning". The term "UVA tanning" is misleading, as the output of a tanning appliance equipped with low-pressure fluorescent lamps always contains some UVB, which is critical for the induction of a deep, persistent tan. With the advent of low-pressure fluorescent tubes of 150–180 cm length, body-size tanning units became commercially available.

More recently, high-pressure lamps producing large quantities of long-wave UVA (>335–400 nm) per unit of time were marketed; these lamps can emit up to 10 times more UVA than is present in sunlight. Some tanning appliances combine high-pressure long-wave UVA lamps with low-pressure fluorescent lamps.

In the late 1990s the trend was to equip tanning appliances with fluorescent lamps emitting UV that mimicked tropical sun (e.g. the "Cleo Natural Lamps" of Philips Cy, Eindhoven, the Netherlands). These lamps emit a larger proportion of UVB (around 4%). The rationale for solar-like tanning appliances is that with the correct UV energy dosage, tanning sessions might resemble habitual sun exposure with a similar balance between total UV, UVB and UVA (de Winter & Pavel, 2000).

Today, lamps originally designed and intended for industrial applications (drying, polymerization) and which emit UV (UVA, UVB and UVC), visible and infrared radiations in different proportions are available on the general market or may be purchased directly through the Internet where they are advertised for building home-made solaria. Even though they emit artificial UV radiation, these lamps (small convoluted fluorescent tubes fitted to a classic bulb socket) and tubes are not considered tanning appliances and escape technical regulations in those countries where tanning appliances are regulated (for instance, upper limit of 1.5% UVB in France and Sweden).

McGinley *et al.* (1998) measured the UV irradiance of different types of tanning appliances used in Scotland. UVA irradiances ranged from 54 to 244 $W.m^{-2}$ for tanning appliances with type-1 tubes and from 113 to 295 W.m-2 with type-2 tubes, while UVB irradiances were 0.2–1.2 $W.m^{-2}$ for type-1 and 1.1–2.8 $W.m^{-2}$ for type-2 tubes. A difference of a factor of three in irradiance was found to result from variation in the age of the tube.

(b) Medical and dental applications: Phototherapy has been used for medical conditions, including a very large number of skin diseases such as acne, eczema, cutaneous T-cell lymphoma, polymorphic light eruption and, most particularly, psoriasis. The devices used to deliver phototherapy have changed considerably over the years from those emitting predominantly UVB to those emitting predominantly UVA, or narrow-band UVB in recent times.

Psoralen photochemotherapy: This form of treatment (PUVA) involves the combination of the photoactive drugs psoralens (P) with UVA radiation to produce a beneficial effect. PUVA therapy has been successful in treating many skin diseases.

Broad-band UVB phototherapy: The skin diseases most frequently treated with broad-band UVB phototherapy are psoriasis and eczema.

Narrow-band UVB phototherapy: This therapy (TL2 Philipps lamps emitting at 311 nm) has proved to be the most beneficial for psoriasis and looks promising in the treatment of some other skin conditions including atopic eczema and vitiligo, pruritus, lichen planus, polymorphous light eruption and early cutaneous T-cell lymphoma.

Broad- and narrow-band UVB in psoriasis patients: Whilst treatment of psoriasis with PUVA is more widely used and better studied in terms of risk for skin cancer, broadband UVB therapy (280–320 nm) has been used for longer, and in most centres narrow-band UVB therapy (311 nm) is now increasingly used. Indeed narrow-band UVB is viewed by many as the treatment of choice for psoriasis (Honigsmann, 2001). Narrow-band UVB is thought to be more effective than broadband UVB and almost as effective as PUVA in the treatment of psoriasis, and it may become a safer alternative to PUVA for long-term use (Honigsmann, 2001).

Neonatal phototherapy: Phototherapy is sometimes used in the treatment of neonatal jaundice or hyperbilirubinaemia. Although intended to emit only visible light, the lamps used for neonatal phototherapy may also have a UV component (Diffey & Langley, 1986).

Fluorescent lamps: Irradiation of the oral cavity with a fluorescent lamp has been used in the diagnosis of various dental disorders such as early dental caries, the incorporation of tetracycline into bone and teeth, dental plaque and calculus (Hefferren *et al.*, 1971).

Polymerization of dental resins: Pits and fissures in teeth have been treated using an adhesive resin polymerized with UVA.

Other medical conditions: In recent years bright light therapy has emerged as treatment for a number of chronic disorders such as seasonal affective disorder (SAD) (winter depression)

(Pjrek *et al.,* 2004), sleep disorders and the behavioural/activity disorders in dementia (Skjerve *et al.*, 2004). The light boxes used for such treatment can emit light levels up to approximately 10,000 lux (Pjrek *et al.*, 2004; Skjerve *et al.*, 2004), an intensity 5 to 10 times lower than that of bright sunlight. The emission spectrum is variable, and some lamps may contain a small but non-negligible proportion of UVA and UVB (Remé *et al.,* 1996), which however is largely inferior to that of indoor tanning appliances. It is noteworthy that the UV component of the light emitted is not involved in the therapy.

(c) Occupational exposures: Artificial sources of UV are used in many different ways in the working environment: some examples include welding, industrial photoprocesses (e.g. polymerization), sterilization and disinfection (sewage effluents, drinking water, swimming pools, operating theatres and research laboratories), phototherapy, UV photography, UV lasers, quality insurance in the food industry, and discotheques. For some occupations, the UV source is well contained within an enclosure and, under normal circumstances, presents no risk of exposure. In other applications, workers are exposed to some radiations, usually by reflection or scattering from adjacent surfaces. Of relevance, indoor tanning facilities may comprise 20 or more UVA tanning appliances, thus potentially exposing operators to high levels (>20W/m^2) of UVA radiation (Diffey, 1990).

Comparison of UV spectrum from sunlight and from tanning appliances

During a sunny day on the Mediterranean coast, the solar UV spectrum at noon contains 4–5% of UVB and 95–96% of UVA.

When UV output is calculated in terms of biological activity, as estimated by the erythema-effective irradiance, the emission of many tanning appliances is equivalent to or exceeds the emission of the midday sun in the Mediterranean (Wester *et al.,* 1999; Gerber *et al.,* 2002). The UV intensity of powerful tanning units may be 10 to 15 times higher than that of the midday sun (Gerber *et al.,* 2002), leading to UVA doses per unit of time received by the skin during a typical tanning session well above those experienced during daily life or even sunbathing. As a result, the annual UVA doses received by frequent indoor tanners may be 1.2 to 4.7 times those received from the sun, in addition to those received from the sun (Miller *et al.,* 1998). This widespread repeated exposure to high doses of UVA constitutes a new phenomenon for human beings.

In the 1990s, regulations in some countries (e.g. Sweden, France) limited to 1.5% the maximum proportion of UVB in the UV output of tanning appliances. However, in practice, the UV output and spectral characteristics of tanning appliances vary considerably. Surveys in the United Kingdom on tanning appliances operated in public or commercial facilities revealed substantial differences in UV output, mainly for UVB, for which up to 60-fold differences in output have been observed (Wright *et al.,* 1996; McGinley *et al.,* 1998). The proportion of UVB in total UV output varied from 0.5 to 4%, and thus emission spectra similar to that of the sun in the UVB range were sometimes attained (Gerber *et al.,* 2002). These differences are due to tanning appliance design (e.g. type of fluorescent tubes used as sources, materials composing filters, distance from canopy to the skin), tanning appliance power and tube ageing. Tanning appliances in commercial facilities may have a greater output in the UVB range than those used in private premises (Wright *et al.,* 1997). With tube ageing, the output of fluorescent lamps decreases, and the proportion of UVB decreases more rapidly than that of UVA.

European and international positions regarding artificial sources of UV radiation

Full details are given in the Appendix and are summarized below.

Standard for appliances designed specifically for tanning purposes

Appliances designed specifically for tanning purposes are defined according to an international standard prepared by the International Electrotechnical Commission (IEC 60 335-2-27).

This standard was first established in 1985 and further modified in 1990, in 1995 and in 2002. A first amendment was added in 2004 and a second amendment is currently being voted on internationally. This standard regulates all appliances sold worldwide, except for the USA who are regulated by the Food and Drug Administration (FDA).

Appliances emitting UV radiation must belong to one of four types of such appliances, determined by their wavelength spectrum and irradiance efficiency (see Appendix for detail).

National and international scientific policies

Several national and international authorities (ICNIRP, WHO, EUROSKIN, the National Radiological Protection Board [United Kingdom] and the National Toxicology Program [USA]) have adopted explicit positions regarding the use of UV-emitting appliances for tanning purposes. These positions are almost invariably accompanied by recommendations targeting the safety of the customers.

Regulations

Regulations and recommendations by health authorities exist in a dozen countries, predominantly in Western and Northern Europe and the USA. Details of the regulations for each country are given in the Appendix.