

Protecting Workers from Ultraviolet Radiation

Editors:

Paolo Vecchia, Maila Hietanen, Bruce E. Stuck

Emilie van Deventer, Shengli Niu



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ICNIRP Scientific Secretary
Dr. G. Ziegelberger
Bundesamt für Strahlenschutz
Ingolstädter Landstraße 1
85764 Oberschleißheim
Germany
Tel: (+ 49 1888) 333 2156
Fax: (+49 1888) 333 2155
e-mail: info@icnirp.org
www.icnirp.org

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The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an independent scientific organization whose aims are to provide guidance and advice on the health hazards of non-ionizing radiation exposure.

ICNIRP was established to advance non-ionizing radiation protection for the benefit of people and the environment. It develops international guidelines on limits of exposure to non-ionizing radiations which are independent and science based; provides science based guidance and recommendations on protection from non-ionizing radiation exposure; establishes principles of non-ionizing radiation protection for formulating international and national protection programmes.

ICNIRP is the formally recognized non-governmental organization in non-ionizing radiation for the World Health Organization and the International Labour Office, maintains a close liaison and working relationship with all international bodies engaged in the field of non-ionizing radiation protection, and represents radiation protection professionals worldwide through its close collaboration with the International Radiation Protection Association and its national societies.

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Stuck B (USA)

Swerdlow A (UK)

Taki M (Japan)

Veyret B (France)

Ziegelberger G, Scientific Secretary (Germany)

Working Group. This document was prepared by the following SCIV and other experts:

Breitbart E (Germany)

Césarini J-P (France)

de Gruijl F (Netherlands)

Diffey B (UK)

Hietanen M (Finland)

Mariutti G (Italy)

McKinlay A (UK)

Okuno T (Japan)

Roy C (Australia)

Schulmeister K (Austria)

Sliney D (USA)

Söderberg P (Sweden)

Stuck B (USA)

Swerdlow A (UK)

van Deventer E (WHO – Switzerland)

Zeeb H (Germany)

PREFACE

The objective of this book is to provide information and advice on protecting workers from ultraviolet radiation (UVR) exposure. The adverse health effects of both acute and chronic UVR exposures are reviewed, emphasizing solar UVR exposure of the outdoor worker. Epidemiological observations and health consequences concerning exposure to UVR (180-400 nm) are also addressed.

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REFERENCES:

Part I: References cited in the Text and Appendices

Part II: Additional References on UVR Radiation

1. Introduction

Workers may be exposed to ultraviolet radiation (UVR) from the Sun and artificial sources such as specialized lamps and welding arcs. Although indoor workers are normally protected by clothing and eyewear, the same level of protection is not generally achieved for outdoor workers. Outdoor workers receive significant exposure to solar UVR and are thereby at increased risk of the adverse consequences associated with UVR exposure of the eyes and skin. The magnitude of the risk for the skin depends greatly upon climatological factors and personal sensitivity to UVR, the latter incorporating both the color of the skin (referred to as the “skin phototype”) and degree of acclimatization, or adaptation, to UVR. However, this great range of individual susceptibility does not exist for the eye, and people of all racial types are susceptible to cataract and other environmentally related eye diseases.

Exposure guidelines for UVR have been recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) similar to earlier recommendations of the International Radiation Protection Association and the American Conference of Governmental Industrial Hygienist (ACGIH). These guidelines are readily applied to indoor exposures to artificial sources, such as welding arcs and specialized lamps. Although these guidelines for protection (ICNIRP 2004) apply to exposure to solar UVR and to artificial sources of UVR, the challenge of meeting the guideline is far greater for outdoor workers because of the lack of control over the source. The geometry of exposure and constantly changing conditions with sun position determine the solar exposure. The guideline values will rarely be met in the context of outdoor worker exposure, especially at lower latitudes (less than 30 degrees). In either case, a great reduction in exposure can be achieved by a variety of protective measures. A key element in achieving the goal of reduced UVR exposure is worker awareness.

Occupationally exposed workers can be classified into two broad groups; those potentially highly exposed and those receiving low exposure. Highly exposed groups include outdoor workers in the construction industry, recreation workers (e.g. ski resort guides and lifeguards), agricultural and horticultural workers, and fishermen. Occupational groups who spend a small proportion of their employment outdoors belong to the low exposure category and include schoolteachers, police officers, delivery-persons and people in the military. It should be remembered that outdoor workers will generally receive similar exposure to the general public as a result of recreational pursuits. When appropriate, outdoor workers should be supplied with protective items such as hats, sunglasses, protective clothing and sunscreens. For the sun-sensitive worker, the difficulties of achieving substantial reduction to solar UVR exposure to comply with the guidelines, may lead these individuals to withdraw from outdoor occupations either partially or completely.

Workers in a limited number of occupations are exposed to significant levels of UVR in the indoor workplace. These include welders, staff in television studios and on theatre stages, some scientific and medical workers, and workers in the graphics and paper industry and other industries using photocuring equipment.

2. Characteristics of UVR

2.1 Basic Concepts

Ultraviolet radiation, like visible radiation (light) and infrared radiation, is radiant energy. Together, these forms of radiant energy are referred to as “optical radiation.” Light and other forms of optical radiation are distinguished from each other by their wavelength (the distance between crests in the wave that carries the energy). In the optical spectrum, wavelengths are normally quantified in terms of nanometers ($1 \text{ nm} = 10^{-9} \text{ m}$) in the UVR and visible spectrum and in terms of micrometers ($1 \mu\text{m} = 10^{-6} \text{ m}$) in the infrared spectrum. Light is of shorter wavelengths than infrared and UVR is of shorter wavelengths than light. Figure 1 shows the spectral band designations by wavelength for the optical spectrum. In describing the biological effects of optical radiation, the spectrum is frequently divided into seven photobiological spectral bands (CIE 1999). The ultraviolet spectral bands are: UVC (100-280 nm), UVB (280-315 nm), and UVA (315-400 nm). The Sun and artificial light sources emit radiant energy within the optical spectrum, comprising the ultraviolet, visible and infrared (Figure 1).

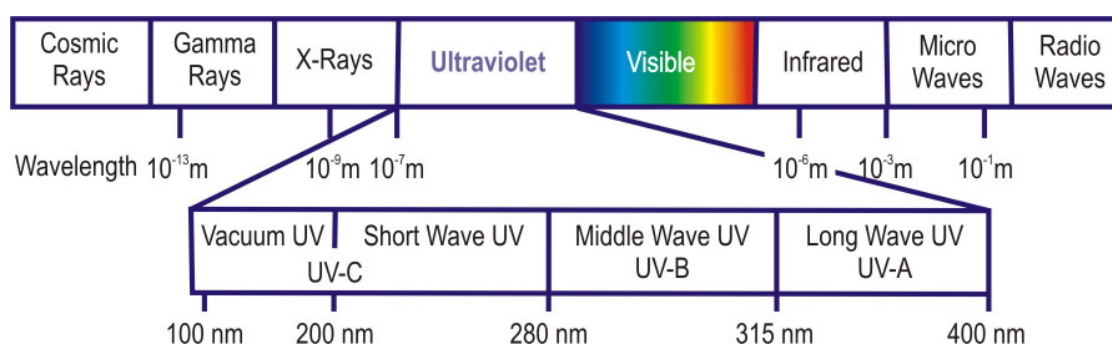


Figure 1. The electromagnetic spectrum and the wavelength bands.

The measurement of optical radiation is referred to as “radiometry.” There are a number of radiometric terms that are used. The “radiant power” in watts (W) describes the rate of energy output of an optical source (rather than the photometric quantity of luminous flux in lumens weighted for the sensitivity of the eye that describes the output of a visible lamp designed for lighting). For a pulsed optical source such as a flashlamp, the “radiant energy” in joules (J) describes the output where one joule is equivalent to one watt delivered over 1 second or 1 watt-second. Two dosimetric quantities quantify human exposure to UVR: “irradiance” and “radiant exposure.” The *irradiance* is the rate of surface exposure in watts per square meter (W m^{-2}) and the *radiant exposure* is the radiant energy per unit area accumulated over a time interval in joules per square meter (J m^{-2}).

2.2 Solar Radiation

Sunlight has played a critical role in the development of life on Earth. The infrared and visible regions of the solar radiation comprise 95 % of the total radiation reaching the Earth’s surface.

The ultraviolet component of the terrestrial solar spectrum comprises approximately 5% of the radiant energy; however this component is largely responsible for the deleterious effects of solar exposure.

2.2.1 The solar spectrum

The Sun emits radiation over all regions of the electromagnetic spectrum - from radio waves to gamma radiation. Optical radiation - UVR, light and infrared radiation - are filtered by the atmosphere. Figure 2 shows the solar spectrum at the Earth's surface. Note that UVR of wavelengths shorter than 290 nm does not penetrate the ozone layer of the Earth's atmosphere.

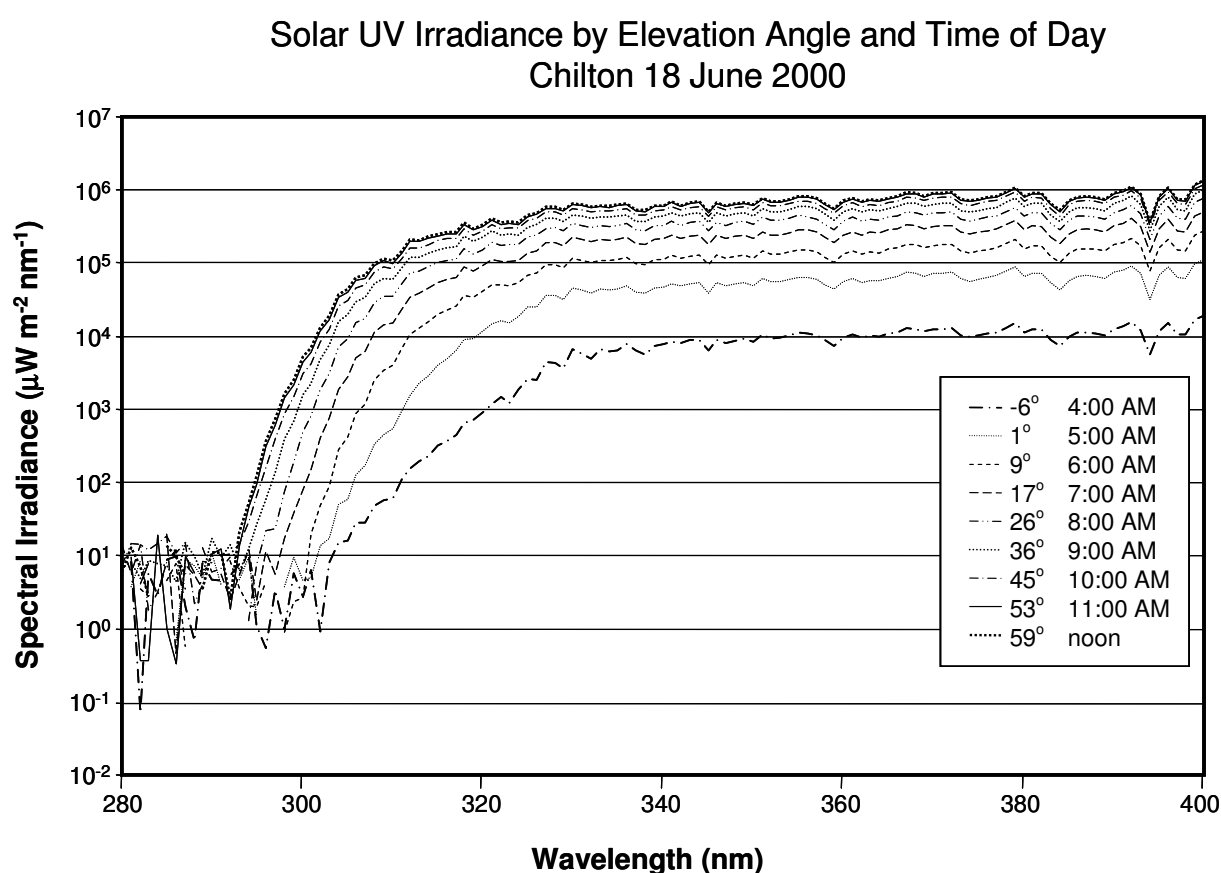


Figure 2. The solar spectrum at the Earth's surface at Chilton, Oxfordshire, UK (52°N). (Data courtesy of the UK Health Protection Agency).

2.2.2 The effect of sun angles and clouds

Both the *quality* (spectrum) and *quantity* (irradiance) of terrestrial UVR varies with the elevation angle of the Sun above the horizon, i.e., the *solar altitude*. The solar elevation angle depends on the time of day, day of year, and geographical location. For example, on a summer's day at

latitude 52 °N, UVB (280-315 nm) radiation comprises approximately 3.5% of terrestrial UVR, and UVA (315-400 nm) the remaining 96.5 %. But since UVB is much more biologically effective than UVA at causing adverse effects, UVB contributes about 80% towards the harmful effects we associate with sun exposure, and solar UVA contributes the remaining 20%.

The quality and quantity of solar UVR are greatly modified by the atmospheric path (Figure 2). Ozone molecules in the stratosphere (~10 to 50 km above sea level) absorb most radiation at shorter wavelengths, and pollutants such as ozone, NO₂ and SO₂, in the troposphere further attenuate the solar UVR (Madronich 1993)

Clouds redistribute and generally reduce the UVR reaching the Earth's surface, although not to the same extent as they do for infrared radiation. The water vapor in clouds absorbs solar infrared much more than ultraviolet, therefore, the risk of overexposure may be increased because the warning sensation of heat is diminished. The ambient annual UVR is about two-thirds that estimated for clear skies in temperate latitudes, rising to about three-quarters in the tropics. Light clouds scattered over a blue sky make little difference to UVR irradiance unless directly covering the Sun, whilst complete light cloud cover reduces terrestrial UVR to about one-half of that from a clear sky. Even with heavy cloud cover the scattered ultraviolet component of sunlight (the skylight that is often called the "diffuse" component) is seldom less than 10% of that under clear sky. More importantly, light overcast or the presence of partial cloudiness generally redistributes more UVR to the horizon sky, thus potentially increasing eye exposure. Only heavy storm clouds can virtually eliminate terrestrial UVR even in the summertime.

The influence of clouds on terrestrial UVR is extremely complex, but it is possible to express the effect on UVR levels from many observations of fractional cloud cover (C). The cloudiness factor (F) is the fraction by which the clear sky UVR level must be multiplied to approximate the level of UVR reaching the ground under cloudy conditions. If the fraction of the sky covered by clouds is C, then $F = 1.0 - 0.5 C$. For example, if clouds cover about 50% (C = 0.5) of the sky, then F = 0.75 or the level of UVR reaching the ground is 0.75 of the level for a clear (cloudless) sky. If the cloud cover is 100% (C = 1), then UVR reaching the ground is reduced to 0.5 of that when no clouds are present. The transmission of UVR through clouds is dependent upon the cloud composition (liquid droplet size) and therefore dependent on the wavelength of the UVR. From the standpoint of outdoor worker exposures to solar UVR, the worst exposure conditions can be with a high sun and light overcast, since the light clouds further scatter the UVR to lower elevation angles, with the result that the ocular exposure is actually greater than on a clear, sunny day (Slaney, 1995).

Altitude plays a role since the thickness of the cloud layer is larger in valleys than in high mountains. Less attenuation of UVR may be observed at high altitude but it is important to note that air pollution and ozone concentration may mask this net change due to altitude alone. However, even under undisturbed conditions an increase of only approximately 7 % per km elevation would be expected.

Reflection of solar UVR from most ground surfaces is normally less than 10%. The main exceptions are gypsum sand, which reflects about 15-30%, surf, which reflects about 20%, and snow, which can reflect up to 90%. Calm water reflects both the direct UVR from the Sun as well as the diffuse component on UVR from the entire sky. Hence the fraction reflected can vary from about 5% if much of the sky is blocked to about 20% if the entire sky is visible from the

water surface. It is typical for 20% to be reflected from choppy water. Since UVR passes easily through water, swimming in either the sea or open-air pools offers little protection against sunburn (Diffey 1999).

Specialized biologically weighted radiometric quantities used to describe and quantify risk from UVR exposure are defined in Appendix A.

2.3 Artificial Sources

Sources of optical radiation can be characterized by an arc discharge (e.g. welding arc, metal halide lamp), incandescent lamps (e.g. tungsten halogen lamp) and lasers (e.g. excimer laser). Artificial sources may provide additional exposure that may be elective (e.g. sunbathing, cosmetic tanning with sunbeds, or medical therapy) or as a consequence of occupation (e.g. electric arc welders) (McKinlay et al 1988, Sliney and Wolbarsht 1980).

2.3.1 *Germicidal lamps*

The low pressure mercury-discharge lamp is often used for the purpose of disinfection. Such lamps are very efficient emitters of 254 nm radiation (UVC). The quartz envelopes of some lamps in this category also may transmit 185 nm radiation. This type of lamp emits minimal amounts of visible and infrared radiation.

2.3.2 *Fluorescent lamps*

The most common application of the low-pressure discharge is the fluorescent lamp. Light is produced by conversion of the 254 nm mercury emission to longer wavelength radiation by means of a phosphor coating on the inside of the glass envelope of the lamp. Lamps are available with many different phosphors and envelopes to produce a wide range of spectral emissions covering the visible (light), UVA and UVB regions. While the continuum emissions of fluorescent lamps are characteristic of the phosphors, the narrow peak, spectral emissions are dominated by the characteristic line emission spectrum of the low-pressure mercury vapor discharge.

2.3.3 *General lighting fluorescent lamps*

Lamps intended for general lighting purposes are available in a range of physical sizes, powers and phosphors to emit visible radiant energy. The range of phosphors includes a large selection of "near white" and "special color" lamps. Detailed spectral analysis of the UV emissions of different general lighting fluorescent lamps have shown that, in general, UVB and UVC emissions are extremely low due to the marked attenuation of wavelengths less than 320 nm afforded by the glass envelope. A plastic cover (diffuser) placed over the lamp eliminates effectively UVR.

2.3.4 *Metal halide and mercury lamps*

Metal halide lamps along with medium pressure mercury vapor lamps are used for general illumination and for health-care applications, including the phototherapy of skin diseases. The

spectral emissions of the discharge are in the visible spectrum (blue, green and yellow) and a large amount of UVR is also generated. The addition of metal halide to the mercury vapor enhances the emission in the UVR.

2.3.5 Xenon lamps

The spectral emission of xenon lamps, closely matches that of sunlight for wavelengths shorter than the infrared (760 nm). This enables their use as solar radiation simulators, for example, in investigating patients with skin diseases induced or aggravated by sunlight. Large amounts of UVA, UVB and UVC are emitted by unfiltered lamps, to the extent that they can present a significant health hazard if incorrectly used. Xenon lamps are also used in high intensity endoscopic illuminators.

2.3.6 Quartz halogen lamps

Quartz halogen (or tungsten halogen) lamps are widely used in special illumination applications, e.g., for specialized task lighting demanding high localized illumination and in instruments such as endoscopes. The quartz envelope permits the emission of UVR that may present a hazard in some circumstances.

2.3.7 Welding arcs

Electrical welding arcs produce hazardous levels of UVR that depend upon the arc current, the shielding gas and the metal being welded (Cox et al 1987, Hietanen and Nandelstadh 1998, Tenkate and Collins 1997).

2.3.8 Ultraviolet lasers and light emitting diodes (LEDs)

Lasers operating in the UVR spectral region are used in medical environments for diagnostic and treatment procedures. For example, the argon fluoride laser operating at 193 nm is commonly used for corneal refractive surgery procedures. UVR emitting LEDs are relatively new UVR sources (solid-state miniature lamps) with growing applications. LEDs operating in the UVR are used in industry and research for photobiological, fluorescence detection, and materials research.

2.3.9 Optical components and filtering

Optical projection systems employing filters, mirrors, lenses and optical fibers can alter the concentration and the spectral distribution of the optical sources. Lamps will often be used in conjunction with optical glass filters to remove unwanted parts of the emission spectrum. The transmission of filters can change with age, particularly in the UVR spectral region. Short wavelength UVR is preferentially absorbed with increasing age. Glass filters are at risk of breaking if they become excessively hot. This can cause a hazard as workers may be exposed to harmful, short-wavelength UVR.

3. Biological and Health Effects

3.1 Biologically Significant Exposure: Dosimetry

In photobiology, the concept of a biologically effective dose is of critical importance. Since not all wavelengths of UVR are equally effective in producing a biological effect, an action spectrum $A(\lambda)$, which defines the relative effectiveness of different wavelengths, is determined. This relative response curve is generally normalized to provide a maximal value of 1.0 at the wavelength of maximal tissue sensitivity. When considering health effects of UVR, an effective exposure rate (i.e., irradiance) E_{eff} (or the exposure summed over time, i.e., the effective radiant exposure H_{eff}) is calculated by spectral weighting as follows: the spectral irradiance E_{λ} at the surface of the exposed biological tissue is mathematically weighted against the action spectrum of the biological response which is a function of the wavelength $[f(\lambda)]$ across the relevant spectrum (e.g., from 200 nm to 400 nm) as is shown in Appendix A.

3.2 Biological Effects on the Skin

Ultraviolet radiation is absorbed to varying degrees by all constituents of living organisms and so, in the epidermis by nucleic acids (DNA, RNA), proteins, and chromophores dispersed in the cytosol and membranes. Interactions with biomolecules will result in absorption of specific UV wavelengths by corresponding molecular structures and result in production of excited state. The primary product generated by UV absorption is a reactive species in an excited state or free radical.

The peak absorption of DNA occurs at around 260 nm with a sharp drop in absorption through the UVB range (several orders of magnitude). No absorption is detected for wavelengths longer than 325 nm.

Aromatic amino acids, like tryptophan, absorb in the UVB and extend into the UVA range. The excited state may transfer the energy to oxygen of which the different excited states (singlet superoxide ion, hydroperoxide, hydroxyl ions) will react with all biological structures, inducing damages. Oxidative damage by these reactive oxygen species may be prevented by scavenger molecules already present in the cell or by a specific anti-oxidative network of enzymes. Damage to DNA results from the direct absorption of UVB radiation or from oxidation by reactive oxygen species. Formation of cyclobutane type pyrimidine dimers were the first type of UV-induced base damages to be identified and are the most frequent lesion induced by UVC and UVB. Also the 6-4 pyrimidine dimers have been identified (10 times less frequent than cyclobutane type pyrimidine dimers). Single-base damages have a low frequency and oxidation is responsible for a group of lesions induced by the UVA absorption by more general chromophores. They are named 8-OHdG. Their formation peaks in the UVA (345 nm) (WHO 1994).

DNA strand breaks are induced by UVB, UVA and shortwave visible radiation range. The phenomenon is dependent on oxygen. Also absorption of UVA may result in DNA-protein cross-links. All DNA lesions should be repaired before the cell is engaged in division. Several mechanisms are involved and gene inactivation may result from mutation in its structure.

A protein P53, encoded by P53 gene, is activated upon absorption of UVR and is intended to link with nuclear DNA, blocking cell division to allow the DNA to be repaired before replication in the early phase of cell division. Any mutation in the gene structure will result in inactive P53 and so, in unregulated mitosis and skin cancers. “Signature mutations” occur at specific sites in the gene and are specific for the agent responsible for the mutation i.e. UV-induced mutations, which are found in most of the human skin cancers. If DNA damages are too numerous to be repaired, a series of events will be followed by a specific type of cell death, i.e. apoptosis, which follows UVR absorption in the skin where “sunburn cells” can be observed histologically.

Lipoperoxydation of membrane lipids will result in cell damages and cell membrane fractures and cell death. A simple irradiation dose of UV near the MED will result in near 300,000 DNA lesions per cell, most of them being repaired in a few hours. The same dose induces activation or inactivation for 5,000 genes, which can be down or up-regulated. Dimers formations are strong inducers of the neo-melanogenesis responsible for skin darkening. Also DNA damages and repairs are able to induce cell divisions, which contribute to the thickening of the epidermis (Bruls et al 1984). Both neomelanogenesis and skin thickening are responsible for skin darkening, commonly called tanning.

Upon irradiation, several cytokines are liberated or activated or synthesized by keratinocytes. They belong to several categories and responsible for local or systemic inflammatory reactions, for vasodilatation, oedema, and fever.

3.2.1 Structure and physiology of the skin

The human tegument is constituted by three main layers: the epidermis, the dermis and the subcutaneous tissue (Figure 3). Each layer has specific components of epithelial, mesothelial and neural origin.

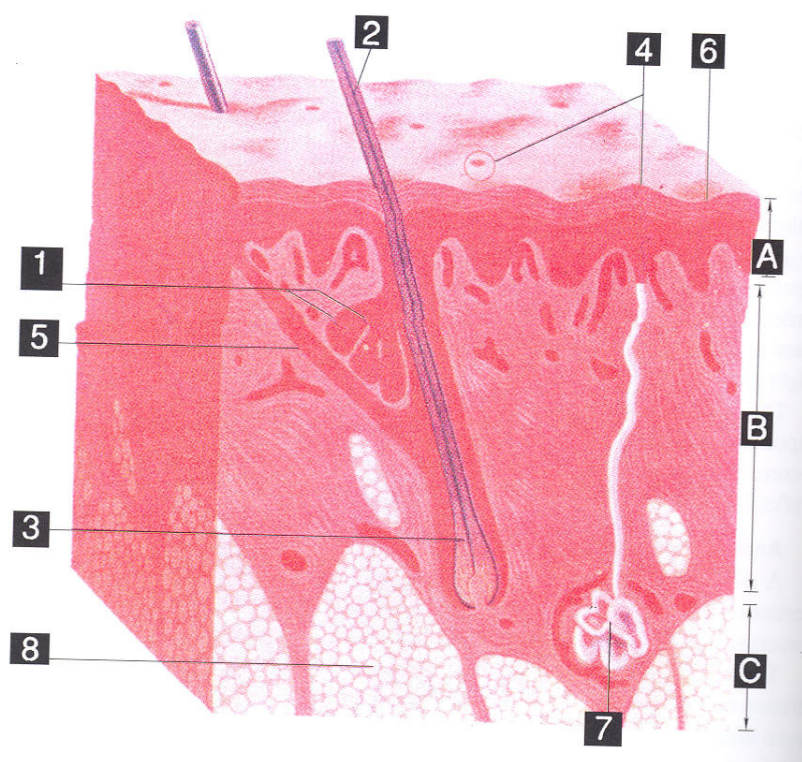


Figure 3. Section of the skin showing the epidermis (A), the dermis (B) and the subcutis (C). (1) sebaceous gland, (2) hair, (3) hair root, (4) surface opening of eccrine sweat duct, (5) erector pili muscle, (6) dermal papilla (in dermis) and (7) eccrine sweat gland and excretory duct, and (8) adipose tissue. (adapted from AGNIR 2002)

The epidermis is avascular and formed by a basal layer of dividing keratinocytes (every three weeks). After division, one keratinocyte is programmed for maturation, forming the Malpighian layers, granular layers and stratum corneum multi-layers. Within the basal layer, melanocytes from neural origin are inserted between basal keratinocytes, their dendrites being in contact with near 50 keratinocytes in the horizontal and vertical planes, forming the melanin unit.

The Langerhans cells (mesenchymal) are located in the upper layers of the stratum Malpighi and are linked through mediators to the near lymph nodes. They constitute the afferent pathway of skin immunity.

Melanocytes and basal keratinocytes cover the basal membrane, a structure which is attached by superficial elastic fibers to the superficial and deep reticular dermis. Collagen and elastic fibers are interlocked to form a dense tissue, which is crossed by vessels (veins and arteries) arriving from a deeper network. In the papillary dermis, the vessels form capillaries which bring nutrients to the epidermis.

Subcutaneous tissues are constituted by fat containing cells. This layer constitutes a mechanical shock absorber between the surface of the skin and the deepest muscles and bones.

Skin appendages are pilosebaceous follicles, eccrine sweat glands and apocrine sweat glands. They are exceptionally affected by UVR damages. In adults, nerve endings are located immediately under the epidermis and are responsible for the pain following UVR-induced effects.

3.2.2 Acute effects on the skin

3.2.2.1 Sunburn

“Sunburn” is an acute injury following excessive exposure to UVR and is most pronounced for lightly pigmented skin types. Sunburn is actually not caused by heat or caustic chemicals, but is the result of a phototoxic (actinic) effect in the skin. Unlike the other burns, sunburn is not immediate. Skin redness reaches a maximum at about 8-12 hours after exposure and fades within a few days. The red appearance of the skin (erythema) results from an increased blood content near the skin’s surface. The non-adapted (“untanned”) skin of very lightly pigmented Caucasian subjects will normally show signs of a mild reddening after about 4 hours following only a half-hour exposure to midday summer sunshine in mid-latitudes. Higher doses may result in pain and skin swelling (edema) with blistering, and after a few days, peeling. Sunburn sensitivity varies substantially with skin complexion and color, and this is reflected in the solar exposure time required to induce a sunburn reaction--from 15-30 minutes of midday summer sunshine to 1-2 hours exposure for moderately pigmented skin; and those with darkly pigmented skin may not clearly show a sunburn for a full day exposure. Skin specialists frequently group individuals into one of six sun-reactive skin types (Table 1), and these skin types fall into three more significant groups based upon how well individuals produce the pigment, melanin, in their skin (see next section) (Joint ISO/CIE 1999/1998, Fitzpatrick TB et al 1995, Diffey 1994, Parrish et al 1982).

Specialized measurement quantities are useful when describing sunburn sensitivity. A person’s Minimum Erythral Dose (MED) is defined as the UVR exposure that will produce a just perceptible erythema 8-24 hours after irradiation of the skin. It is very important to recognize that the MED *is specific to one individual* and it varies with the source of UVR the tanning capacity and any adaptation from previous exposures. Because the MED measure refers only to an individual, there exists a related, standardized quantity for source measurement: the Standard Erythral Dose unit (SED) to quantify the ability of a source to produce erythema. This unit is widely used in dermatology and specialized fields to measure erythemally effective irradiances ($\text{W}\cdot\text{m}^{-2}$ eff.), or SEDs per hour. Still another, related quantity is the Global Solar UV Index used in public health to describe the risk of sunburn with weather and sun position. A UVI of 1.0 is slightly less [10% less] than one SED per hour. Both quantities are standardized by the International Commission on Illumination (CIE) and the International Standards Organization (ISO) as explained in the Appendix A (Joint ISO/CIE 1999/1998).

3.2.2.2 Tanning and adaptation of the skin

The wide range of susceptibility to solar exposure among phototypes (Table 1) is due largely to the two types of melanin (eumelanin and pheomelanin), (Young 2004, Césarini 1988),

Eumelanin (black melanin) is produced by melanocytes upon alpha-MSH adsorption on MC1R gene product (receptor) at the surface of the melanocytes. Pheomelanin (red melanin) is produced in melanocytes bearing MC1R variants. Pheomelanin absorb UV photons and produce reactive oxygen species (ROS) which are phototoxic. Eumelanin (stable free radical) absorb UV photons and scavenge free radicals and are photoprotective. All individuals produce eumelanin and pheomelanin in different ratios according to genetic makeup and as a consequence present large differences in solar sensitivity and skin cancer incidence. In addition, darker skin types have more efficient DNA repair than the skin phototypes I and II (Sheehan et al 2002).

Skin adaptation from frequent UVR exposure is not only characterized by the obvious effect of skin darkening (“tanning” or “melanogenesis”), but also by skin thickening (Table 2). Thickening of the outermost layers of the skin (epidermis and stratum corneum) takes place as an adaptation to UVB-related damage. This can be a 3 to 5-fold thickening of the stratum corneum within one to seven weeks after several exposures to UVB, and returns to normal about one to two months after ceasing exposure. This thickening after sun exposure leads to a significant increase in UV protection by a factor of five or greater, and in lightly pigmented skin types, thickening is probably more important than tanning in providing protection. The thickening of the skin after prolonged tanning protects sensitive cells (basal keratinocytes, melanocytes) by absorbing UVB radiation before they reach the basal layer of the epidermis. After some shedding (peeling) of the stratum corneum, the basal layer can be directly stimulated by UVB and thus the thickening or protective processes recur and reach a steady state. However, in darkly pigmented individuals it is likely that skin pigmentation is the most important means of protection against UVR.

Tanning becomes noticeable within a day or two after sun exposure, gradually increasing for several days and persisting for a week. Although a tanned skin does confer a degree of protection, this seems to be no more than a factor of two to three in the absence of skin thickening. The wavelengths of the radiation that induce tanning are very similar to those of radiation producing erythema. Table 1 describes the range of skin types and sensitivity to UVR effects. Subjects with sun-reactive, melano-compromised (skin types I and II) are poor tanners compared to those with melano-competent (skin types III and IV) who tan well. Melanogenesis can be stimulated in individuals who tan well with solar UV doses that were considerably below the erythemal doses in the UVA region.

Table 1. Classification of skin types based on their susceptibility to sunburn in sunlight and their ability to tan. Modified after Fitzpatrick and Bologna, 1995

Skin phototype	Sun sensitivity	Sunburn susceptibility*	Tanning achieved	Classes of individuals
I	Very sensitive	Always sunburn: < 2 SED	No tan	Melano-compromised
II	Moderately sensitive	High: 2 – 3 SED	Light tan	Melano-compromised
III	Moderately insensitive	Moderate: 3 - 5 SED	Medium tan	Melano-competent
IV	Insensitive	Low: 5-7 SED	Dark tan	Melano-competent
V	Insensitive	Very low: 7-10 SED	Natural brown skin	Melano-protected
VI	Insensitive	Extremely low: > 10 SED	Natural black skin	Melano-protected

*The ranges of SEDs are not prescriptive but only indicative

Protecting Workers from Ultraviolet Radiation

Table 2. Skin phototypes and sun sensitivity factors with and without adaptation

Skin Phototype	MED without adaptation	MED with adaptation*
I-II (Celtic)	2 SED	6 SED
III-IV (Mediterranean)	7 SED	10 SED
V (Asians)	10 SED	60 SED
VI (Black)	15 SED	80 SED

* “SED with adaptation” implies three weeks of tanning from solar exposure without erythema. (Bech-Thomsen and Wulf 1996, Willis 1988, Césarini – personal communication 2005).

3.2.2.3 Photosensitizers and the working environment

A photosensitizer is a chemical compound which absorbs optical radiation (generally UVR) and transfers the energy to reactive biomolecules. These reactive biomolecules or reactive species can produce a toxic reaction at doses well below those that induce sunburn, keratitis or other biological responses. Some photosensitizers are also photo-allergens. It’s important to distinguish between a photosensitize reaction and that of a photo-allergen. In a photo-allergic reaction, the incident energy triggers the immune response. Phototoxic reactions are usually localized to the body surface at the site of exposure. In a photoallergic reaction, the extent of the effect is far beyond the site of exposure. Clinical investigations and use of a battery of tests are necessary to identify with precision the origin of the abnormal reactions. In most of cases, a phototoxic reaction is proportional to the concentration of the photosensitizer and to the magnitude of UV exposure. On the contrary, the magnitude of the photoallergic reaction is not proportional to the concentration of the photosensitizer and to the magnitude of UV exposure but depends on the amplitude of the immunologic reaction. Some individuals who have been exposed to photosensitizers and have experienced phototoxic reaction may present permanent skin reactions when exposed only to the Sun. They are called “chronic photo-reactors”.

Some chemicals can enhance the sensitivity of the skin to UVR (most notably, UVA) through what is known as “phototoxicity”. Photosensitizers like certain drugs, plant materials, perfumes and cosmetic constituents, dyestuffs, polycyclic hydrocarbons in wood preservatives, coal tars, pitch and pollutants, sunscreen and printing ink materials can enter the skin from the surface or through other routes to produce phototoxic reactions. Photosensitizers can be found in domestic work environments (Table 3), outdoor workplaces (Table 4), and in industrial working places (Table 5). In addition, the strongest photosensitizers are often administered for medical purposes, and workers exposed to UVR should be aware of this potential (Table 6).

Table 3. Photosensitizers in the domestic work environment

Sources	Active Ingredients
Bacteriostats in soaps	Halogenated salicylanilides;
Wood preservative	
Vegetables	Psoralens in celery and parsnips

Table 4. Photosensitizers in the outdoor work environment

Sources	Active Ingredients
<i>Plants (garden and countryside)</i>	
Umbelliferae:	giant hogweed (<i>Heracleum mantegazzianum</i>)

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	cow parsnip (<i>Heracleum sphondylium</i>)
	wild parsnip (<i>Pastinaca sativa</i>)
	tromso palm (<i>Heracleum laciniatum</i>)
Rutaceae:	common rue (<i>Ruta graveolens</i>)
	gas plant (<i>Dictamnus alba</i>)
	Bergamot orange (<i>Citrus bergamia</i>)
Moraceae:	fig (<i>Ficus carica</i>)
Plants containing furocoumarins:	psoralen, 8-methoxypsoralen, 5-methoxypsoralen, pimpinellin, sphondin, angelicin.
General	
Perfumes and cosmetics:	5-methoxypsoralen (Bergapten) in oil of Bergamot, musk ambrette, 6-ethylcoumarin.
Sunscreens:	p-aminobenzoic acid (PABA), ethoxyethyl-p-methoxycinnamate, isopropylidibenzoylmethane, butylmethoxydibenzoylmethane.
Disinfectants and Antiseptics:	Methylene blue, eosin and rose bengal
Tattoos:	cadmium sulphide.

Table 5. Photosensitizers in the industrial/working environment

Sources	Active Ingredients
Anthraquinone based dyes:	benzanthrone; Disperse Blue 35.
Polycyclic hydrocarbons:	pitch, coal tar, wood preservatives, anthracene, fluoranthrene.
Drugs:	chlorpromazine, amiodarone
Plants:	giant hogweed, psoralen
Printing ink:	amyl-o-dimethylaminobenzoic acid
Animal feed supplement:	quinoxaline-n-dioxide

Table 6. Major photosensitizers administered for medical purposes

Sources	Active Ingredients
Drugs	
Antibacterial:	tetracyclines, sulphonamides, nalidixic acid, 4-quinolones
Tranquilizer:	phenothiazines (chlorpromazine)
Antidepressant:	protryptiline
Diuretic:	chlorthiazides, furosemide
Antiarrhythmic:	amiodarone, methyl dopa, quindine, propranolol
Anti-inflammatory:	ibuprofen, azapropazone, naproxen
Antifungal:	griseofulvin
Bacteriostat:	halogenated salicylanilides, bithionol, buclosamide
Topical antifungal:	fentichlor, hexachlorophene
Antimalaric:	quinine
Photo Therapies	
Photochemotherapy:	8-methoxypsoralen, 5-methoxypsoralen, trimethylpsoralen, khellin
Photodynamic therapy:	Photofrin II

3.2.2.4 Reactions revealing chemical photosensitivity

Prickling and burning

Coal tar, pitch and a number of their constituents combined with exposure to sunlight or UVA alone, produce immediate prickling or burning sensations in the exposed skin. Longer exposures increase the intensity of the 'pitch smarts' and produce erythema and a wheal and flare reaction which subsides an hour or so after the exposure to leave erythema restricted to the exposed area of skin. The early phase erythema may also fade but develops again, reaching a maximum between 24 and 48 h. Following the inflammatory reaction, skin darkening (hyper-pigmentation) will develop after a few days. The hyper-pigmentation can be in bizarre patterns if due to splashing (e.g., with wood preservatives).

Intense sunburn

An exaggerated sunburn reaction is associated with a number of systemic drugs, but typically with moderate doses of demethylchlortetracycline or high doses of other tetracyclines such as doxycycline and chlorpromazine. UVR exposures that are normally harmless (e.g., from UVA) produce mild sunburn and those that are normally just erythemogenic result in severe reactions.

Blistering

Blistering reactions may occur from UVR photosensitization that is most typical of contact with plant psoralens. The reactions are initiated by contact with the sap from a psoralen containing plant and exposure to sunlight. Erythema, possibly painful, distributed in a pattern clearly related to contact with the plant, is first seen about 24 h later. Blisters develop during the next 24-h which may coalesce to produce a localized pattern of response (sometimes reproducing leaf imprints), but subside within days. Pigmentation abnormalities may develop and persist for months. The intensity of erythema and blistering depend on exposure dose and amount of photosensitizer in the skin. When these are low, only erythema may occur with a latent period of 72 h or more, followed by hyper-pigmentation.

3.2.3 Chronic effects on the skin

3.2.3.1 Photoaging

Photoaging from occupational exposure has traditionally been particularly observed in fishermen and farmers in sun exposed sites such as the face and the back of the neck and hands. The clinical signs of a photo-aged skin are dryness, deep wrinkles, accentuated skin furrows, sagging, loss of elasticity, mottled pigmentation and the development of tiny but highly visible, superficial blood vessels (telangiectasia). These characteristics reflect profound structural changes in the dermis. It is not yet clear which wavelengths are most responsible for photo-aging, but some research studies point to solar UVA and even infrared radiation exposures as contributing factors.

3.2.3.2 Skin cancers

The three common forms of skin cancer, listed in ascending order of severity are: basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and malignant melanoma (MM). Around 90% of skin cancer cases are of the non-melanoma variety (BCC and SCC) with BCCs being

approximately four to eight times (depending on latitude) as common as SCCs. Exposure to UVR is considered to be a major etiological factor for all three forms of cancer (IARC 1992). For basal cell carcinoma and malignant melanoma, neither the wavelengths involved nor the exposure pattern that results in risk have been established with certainty; whereas for SSC, both UVB and UVA are implicated and the major risk factors seem to be cumulative lifetime exposure to UVR and a poor tanning response. The risk of developing skin cancer varies greatly with skin type, and more than 90% of skin cancers are found in melano-compromised persons (Table 1). These individuals should be advised to choose occupations where UVR exposure is minimal. When UVR exposure is unavoidable, protective measures (hats, clothing) is strongly recommended. Therefore, persons who readily sunburn are also more prone to develop skin cancer. Precursor lesions of SCC known as actinic keratoses are common in fair-skinned outdoor workers by the age of 50 to 60 (depending upon latitude).

3.3 Effects on the Eye

3.3.1 Structure and physiology of the eye

Exposure of the eye to UVR is associated with a variety of disorders, including damage to the eyelids, cornea, lens and retina (Figure 4).

The eye, situated behind the eye lids, is deeply buried in a groove on the face. This anatomical feature strongly protects the eye from UVR from most directions. The eye is not well protected from UVR directly incident from the front or the side.

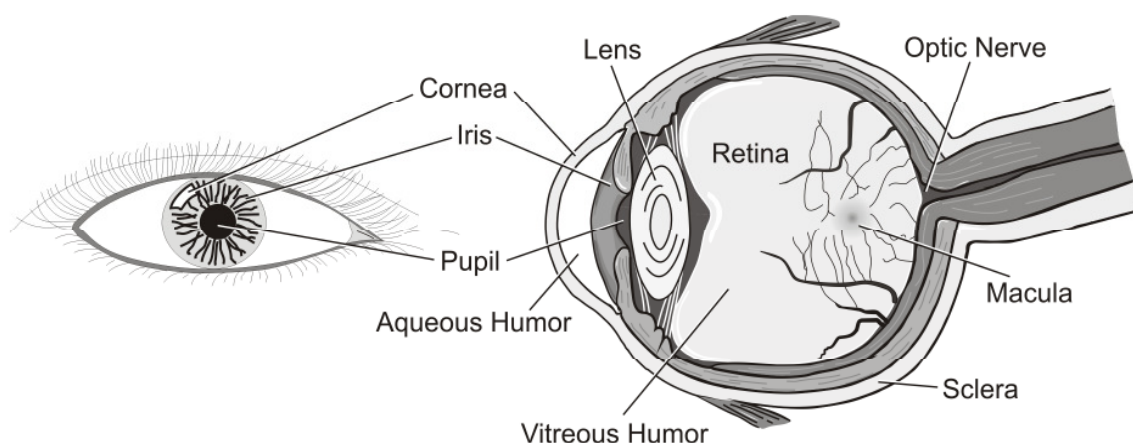


Figure 4. The anatomy of the human eye

During squinting or closure of the eye, the upper and lower eyelids protect a portion or the entire eye from UVR exposure.

The ocular media partially transmit and refract UVR. The refraction may concentrate directly incident radiation to a higher irradiance. Therefore, ocular effects of the Sun are primarily located in the lower nasal part of the outer eye (Figure 5).

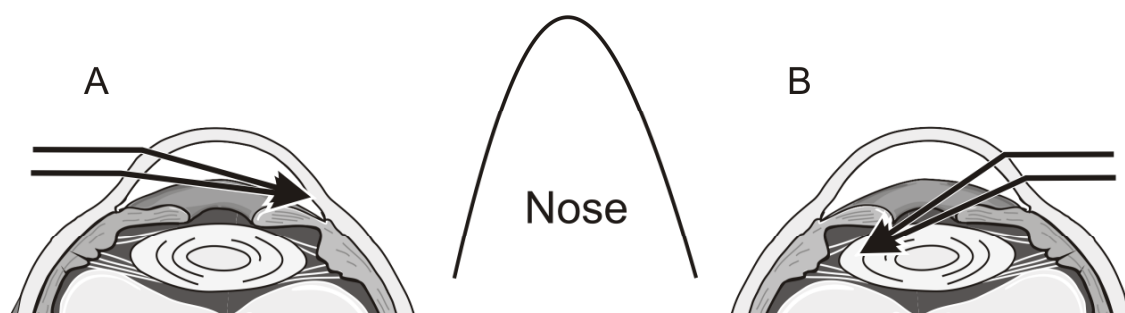


Figure 5. Concentration of UVR in the eye by refraction (the Corneo Effect) into the corneal limbus (A) and nasal area of the lens (B)

The UVR reaching internal structures of the eye is attenuated depending upon the wavelength of incident radiation (Figure 6).

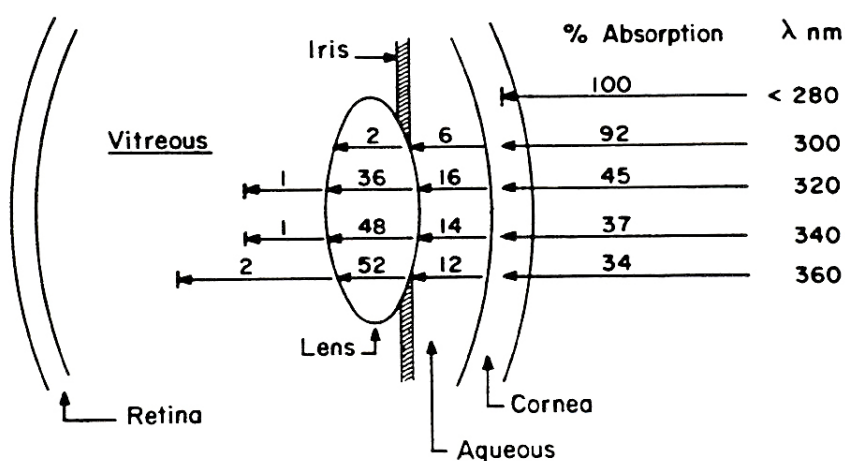


Figure 6. Penetration of UVR into the eye (adapted from Sliney and Wolbarsht 1980)

Radiation with wavelengths shorter than 290 nm is almost entirely absorbed by the cornea, Figure 6. Further, radiation in the range 300-370 nm is almost entirely attenuated in the lens. There is a strong increase of UVR attenuation by the lens with increasing age. If the lens is

removed (cataract surgery) without implantation of an UVR absorbing lens or if there is no lens (i.e. aphakia, which is rare), a significant fraction of the incident UVR (290 - 400 nm) may reach the retina.

The cornea does not adapt to repeated exposures like the skin (by thickening of the stratum corneum and epidermis). Therefore, the cornea is equally vulnerable day after day to the same exposure to UVR.

The effects of UVR on the eyelids are equivalent to those described for the skin. For this reason only adverse effects of UVR to the eye will be considered here.

Since the transparent media of the eye do not have any melanin pigment (as in the skin), there is no correlation between the UVR sensitivity of the eye and skin type.

3.3.2 Acute effects

An unprotected eye exposed to UVR from the sunlight reflected from light sand or snow during one day may accumulate a sufficient dose to cause an adverse effect in the cornea of the eye. As with sunburn of the skin, the symptoms are delayed for several hours. Within six hours such an exposure gives rise to a gradual transition symptoms form a feeling of itchiness, “sand in the eye” sensation, increased tearing, to severe pain and photophobia (light sensitivity). This is caused by an inflammatory reaction in the cornea and conjunctiva known as photokeratoconjunctivitis, which leads to a swelling and loss of the superficial cells in the cornea and the conjunctiva. Within 24-48 hrs, the pain decreases and the light sensitivity disappears. This condition is popularly referred to as “snowblindness” or “welders flash.”

In addition to corneal injury, laboratory studies have demonstrated acute cataract formation from UVR at wavelengths greater than 310 nm emitted by artificial or laser sources (Pitts et al 1977, Söderberg et al 2002, Ayala 2005, Hockwin et al 2002). In the unusual situation where the UVR absorbing lens or lens implant is not present, retinal injury is possible for wavelengths greater than approximately 300 nm (Zuclich 1989, Ham et al 1982)

3.3.3 Chronic effects

Pterygium is a fibrous ingrowth of the cornea of tissue making the cornea opaque. Epidemiological data strongly support a correlation between chronic exposure to UVR and pterygium (Taylor 1992, Taylor 2000, Sliney 2000).

A pingueculum is a non malignant connective tissue tumor in the conjunctiva. Droplet keratitis is a focal deposition of lipids in the cornea with an adverse effect on transparency. Both of these conditions have been epidemiologically associated with exposure to UVR (Lim et al 1998, Taylor 1992).

Development of cataract, a clouding of the lens that disturbs vision, is part of the natural ageing process. Epidemiological data show an increased risk for cortical cataract with UVB exposure from the sun (Taylor 1988, McCarty et al 2002, Sasaki et al 2002). The prevalence of the blinding disease of cataract world-wide exceeds 50 million (Brian 2001, Thylefors 2001, WHO 1994). Animal experiments have clearly shown that UVR exposures produce cataracts, but experts disagree on the degree of importance played by environmental solar exposure (Sliney 2002).

3.4 Systemic Effects

3.4.1 *Production of vitamin D₃*

The best-established beneficial effect of solar ultraviolet radiation on the skin is the synthesis of vitamin D₃ (Webb and Holick 1988, Webb et al 1989). Solar radiation in the UVB waveband photochemically converts 7-dehydrocholesterol in the epidermis to previtamin D₃, which is then converted to vitamin D₃. Sunlight regulates and limits further production of vitamin D₃ in the skin to preclude a toxic level. During midday hours in the tropics or during the spring and summer in more temperate climates, only brief sub-erythral exposures to sunlight are required to synthesize vitamin D₃. In this case, less than 15 minutes of solar UVR exposure on the hands, arms and face fulfils this requirement. However, in some latitudes outside the tropics, there may be insufficient ambient UVB during the winter for this process, and this deficiency has a greater impact for persons having highly pigmented skin and elderly persons (Webb et al 1988).

Vitamin D is known to be essential for the body's proper uptake of calcium, which is important for bone and musculoskeletal health. There is also evidence of an increased risk of autoimmune diseases, including multiple sclerosis, type-1 diabetes and rheumatoid arthritis with low vitamin D intake or low UV exposure, respectively. Some recent epidemiological studies suggest a link between a number of cancers and low vitamin D levels. There is limited evidence for a possible association with prostate, breast and other cancers, but somewhat stronger evidence for colon cancer. At present, however, the evidence is insufficient to establish a causal relationship and the questions on what is the optimal level of vitamin D and what is the amount of UV needed to maintain an adequate vitamin D level still remain difficult to answer (reviewed in ICNIRP 2006).

3.4.2 *UVR immune effects*

Through photochemical reactions, UV radiation can alter various organic molecules in the skin and these molecules may become dysfunctional and 'foreign' to the skin. An important task of the body's immune system is to seek out and destroy any "foreign intruders," and it is therefore conceivable that UV radiation could trigger unwanted immune reactions against the skin (this might actually cause 'sun allergy') (Cooper et al 1992). It has, however, been established that UVB exposure reduces specific immune reactions in the skin of healthy people and this is likely to constitute a healthy response to avoid any undesired immune reaction against the UVR exposed skin. This effect is usually only temporary, but it can have clear drawbacks when it coincides with an infection or with abnormal cell growth. For these conditions, UVR exposure of the affected area should be minimized.

Not only infections in the skin can be aggravated, but also internal infections. The common 'cold sore' that is evoked by sun exposure appears to be a good example of an infection (by stimulating the Herpes simplex virus) in humans brought forth by UVB exposure. In all, there is much evidence that UV radiation affects immunity and, because of that, can aggravate infections and allow the development of (skin) cancers. Some systemic diseases such as Lupus erythematoses can also be aggravated by UVR exposure.

4. Occupational Exposure to Solar Ultraviolet Radiation

4.1 Factors that Influence Human Exposure to Solar UVR

Humans have evolved in sunlight, and therefore adapted in several ways to natural conditions of exposure. By contrast, exposures from many types of artificial sources such as welding arcs may bypass these adaptations. Since anatomical and behavioral factors tend to reduce the severity of sunlight exposure, occupational exposure to sunlight is necessarily treated in this separate section.

The solar UVR to which an individual is exposed depends upon:

- The ambient solar UVR
- The fraction of ambient exposure received on different anatomical sites
- Behaviour and the duration spent outdoors

The UVR exposure doses to the eye and skin are further modified by the use of personal protection such as sunglasses, goggles, hats, clothing and sunscreens.

Estimates of personal exposure have been obtained in two ways: by direct measurement using UVR sensitive dosimeters (e.g. film badges); or by independent determination of these three variables, either by measurement, modeling, or a combination of both. The results obtained from a number of studies indicate that although indoor workers in northern Europe are normally protected from indoor UV sources, they receive an annual solar exposure of around 200 *standard erythema dose (SED) units* mainly from weekend and holiday exposure, and principally to the hands, forearms and face. This value is approximately 5% of the total ambient available. Ocular exposure rarely exceeds the ICNIRP guideline (ICNIRP 2004) for daily exposure except for unusual conditions, e.g. reflections from snow.

Outdoor workers at the same latitudes receive about 2 to 3 times these exposure doses, whilst film badge studies of outdoor workers on the Sunshine Coast in Queensland, Australia (27°S) (Gies et al 1995) suggest that annual exposures would be considerably higher - certainly in excess of 1000 SED per year.

4.2 Anatomical Distribution of Sunlight

The mean percentage of ambient UVR relative to the vertex received at different anatomical sites as measured on rotating mannequins and living subjects pursuing outdoor activities which included tennis, sailing, swimming, walking, golf and gardening are shown in Appendix B. The shoulders generally receive the highest relative exposure for all activities (approximately two-thirds of the vertex), with greater variability between other sites reflecting differences in posture for the different activities.

4.3 Facial Exposure to Solar UVR

The face is particularly prone to solar damage because of its significantly greater exposure compared with other anatomical sites, which are generally covered by clothing when outside. UV film badge studies of solar UVR exposure on the face relative to ambient exposure show

great variation with different sites on the face, posture, behavior, sun position in the sky and any shading. Representative values at different sites on the head are given in Appendix B. The exposure of the nose relative to the reference global UV exposure was shown to drop from 59% to 11% as the head tilts from 0° to 60° to the vertical. Wearing a brimmed hat further modifies the exposure over the face, especially if the hat has a wide brim. A 7 cm hat brim will reduce the UVR facial exposure by a factor of five (Diffey and Cheeseman 1992).

4.4 Ocular Exposure to Solar UVR

Although UVR-sensitive contact lens dosimeters have been developed, they are impractical. However, the sensitive cornea itself has served as a true ocular exposure dosimeter when subtle, transient corneal changes were correlated with ambient UV exposure values (Sloney 1995). Pertinent data have also come from studies of lid opening conditions combined with directional field measurements and different environmental conditions. Ground reflection becomes very significant in these evaluations. Appendix B provides information on the reflectance of ICNIRP/ACGIH-weighted solar UVR and the measured effective UVR (largely UVB) from the sky for a 40° cone field-of-view.

The relative effective UV exposure of the eye as a function of time of day does not show the dramatic variations observed for skin exposure. The variation in lid opening plays a large role. On an overcast day, the eyelids are more open and although the UVB irradiance is reduced by cloud cover, the actual UVB dose rate to the eye from the sky scatter may be hardly reduced (Sloney 1995).

Ocular exposure is far more affected by the geometry of exposure than is skin exposure as shown in Figure 7. The UVR reaching the eye from the Sun is almost limited entirely to indirect UVR that has been diffusely scattered by the atmosphere and reflected from the ground. The geometry of exposures from artificial sources such as lamps, welding arcs or lasers is therefore different from exposures from the Sun.

At sunset, the filtering of UVR and blue light by the atmosphere allows a direct view of the sun. When the solar elevation angle exceeds 10 degrees above the horizon, squinting is observed which effectively shields the cornea and the retina from direct exposure. These factors reduce the exposure of the cornea to a maximum of 5 % of that falling on the exposed top of the head. However, if the ground reflectance exceeds 15 %, photokeratitis may be produced following 1-2 hours of midday summertime exposure. Apart from squinting, the photokeratitis threshold would be achieved in less than 15 minutes exposure for midday summer sunlight. When the sun is high in the sky, ocular exposure to sunlight reflected from snow produces snow blindness.

Although the cornea is more sensitive to UVR injury than the skin, acute UVR injury is not often experienced because of behavioral avoidance of direct sunlight exposure of the eye. Individuals do not look directly overhead when the sun is very hazardous to view, whereas most people may stare at the sun when it is comfortable (and safe) to observe near the horizon.

A brimmed hat or other headwear associated or not with dark sunglasses, will modify greatly the UVR exposure. When wearing sunglasses, the pupil and lids open proportionally to the darkness of the sunglass and peripheral exposure to the eye in the absence of side shields can be substantial.

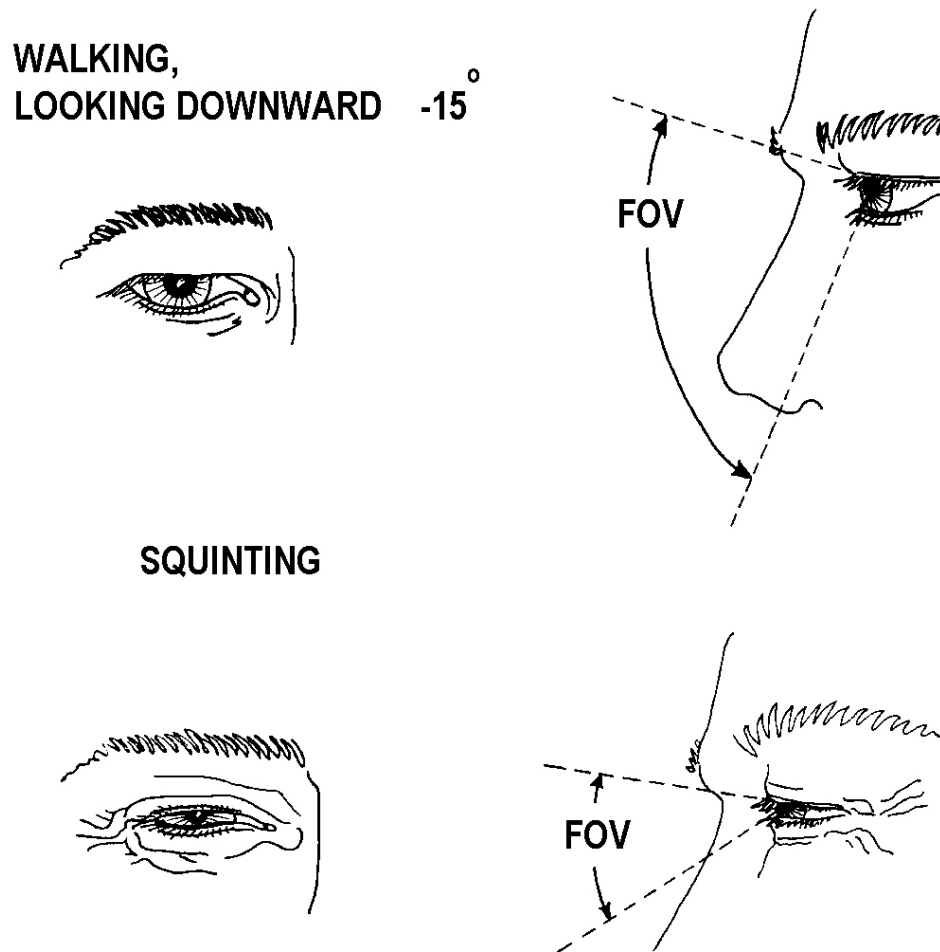


Figure 7. Exposure of the eye is greatly limited outdoors because of squinting and shielding of overhead UVR by the brow ridge (after Sliney 1995)

4.5 Influence of Various Factors on Exposures in Outdoor Occupations

The strong dependence upon the position of the sun (elevation angle or “altitude”) on the exposure received by the eyes and skin plays a major role in determining worker exposure. Since exposure of the eye and skin depend upon posture, exposure duration, the particular environment, daytime and season, the work tasks and shift can greatly impact the UVR dose. As shown below, each factor is not independent of the other factors; hence all factors must be evaluated to determine total worker exposure.

4.5.1 The influence of work task and posture

The work tasks can greatly influence the geometry and duration of exposure. Posture is important. For example, many tasks in traditional agricultural occupations require the worker to bend over, thus favoring exposure of the back and the back of the neck, but thereby reducing exposure to the face. For many tasks performed by fishermen, the exposures will have some similar postural aspects, but the reflection from water and the time of day may result in higher exposure doses to the eye and skin. Outdoor merchants selling produce routinely are upright with their face upward, but nearby buildings and shading structures may greatly reduce solar exposure of the face and eyes.

4.5.2 The influence of task duration, intermittency and shift aspects

Since the ambient UVR exposure is greatest during midday hours, the duration of tasks and duration of lunch breaks can influence the daily UVR exposure. Some tasks are intermittent, e.g. in police work, the periods of outdoor recess for teachers, the outdoor periods of deliverymen, and periods of training exercises for soldiers or sailors. Some fishermen may only have substantial outdoor tasks early in the day or late in the day; whereas, other fishing tasks may be during midday hours. Arctic fishing over ice may lead to unusually high surface reflectance factors. If adaptation is not achieved from regular outdoor work, the risk of severe sunburn, and possibly melanoma, may be an important factor due to the intermittent nature of the outdoor exposure.

4.5.3 The influence of season

Some occupational tasks are highly seasonal, as in horticultural occupations and certain types of outdoor recreational supervision. Outdoor construction and road building tasks are frequently performed only during summer months in higher latitudes because of the impact of ambient temperature upon work. By contrast, some outdoor tasks in fishing, agriculture and winter sports are only performed in winter months when the ambient UVR exposure is low, but ground reflection from snow could be high. Since the risk of over-exposure from solar UVR is very seasonal in temperate climates, the health protection message should be seasonal so as not to be ignored as unrealistic by workers (Sliney and Wengraitis, 2006).

4.5.4 The influence of customary and protective clothing and headwear

Clothing and headwear vary greatly depending upon occupation, ambient temperature, culture, and safety requirements. Most summer clothing provides attenuation factors (protection factors) greater than 10. In one measurement study of over 5000 fabrics, 97% of fabrics had attenuation factors greater than 10 and more than 85% of fabrics had protection factors exceeding 20. Heavy-duty work clothes, such as denim coveralls have UV attenuation factors greater than 10,000. Most textiles absorb more or less uniformly over the solar UVR spectrum. In other words, as with other forms of shade such as trees, canopies and beach umbrellas, most clothing provides principally a quantitative, rather than qualitative (spectral), reduction in cutaneous UVR exposure. Although factors such as, weight, stretch and wetness (and even color in some instances) affect the attenuation factor, the primary factor is the fiber coverage.

4.5.5 Shading

The presence of buildings, trees, mountains and other shading structures can greatly affect the total UVR exposure of the skin and eyes. When the direct view of the horizon sky is blocked, ocular exposure to UVR can be greatly reduced. It is important to realize that most shading structures are designed to reduce direct sun exposure, and are frequently less effective in blocking diffuse sky radiation and ground reflection. One can actually experience sunburn from exposure to diffuse sky radiation whilst shaded from only the direct sunlight.

5. Occupational Exposure to Artificial Sources of Ultraviolet Radiation

Artificial sources of UV radiation are used in many different applications in the working environment. In some cases the UV source is well contained within an enclosure and, under normal circumstances, presents no risk of exposure to personnel. In other applications it is inevitable that workers will be exposed to some radiation, normally by reflection or scattering from adjacent surfaces. Under these conditions it is important that exposures be kept below maximum permissible limits for occupational exposure published by national regulatory authorities (e.g. European Commission 2006), either by administrative and engineering controls or by the use of protective clothing, eyewear and face-shields.

5.1 Factors that Influence Human Exposure to Artificial Sources

Unlike sunlight, most artificial sources do not have a large change in spectrum or intensity during a workday. However, many sources are used only intermittently and the position of the worker with respect to the UVR source can vary greatly. Three principal factors that influence the potential health risk are:

- source spectrum and biologically effective UVR emissions
- distance of the worker from the source
- duration of worker exposure

5.2 Facial and Ocular Exposure

An artificial source, such as a welding arc or lamp, is very frequently within the normal direct field-of-view and gaze angle of the worker. By comparison, it is quite unusual for the outdoor worker to directly view the solar disc. Hence, the ocular exposure can be equivalent to that of the face, and therefore photokeratoconjunctivitis (i.e. “welders' flash”) can readily occur within shorter exposure durations than required for a noticeable erythema (“sunburn”) of the face.

5.3 Examples of Exposure in Different UVR Applications

Common sources, their relative hazard and safety precautions are summarized in Table 7.

Protecting Workers from Ultraviolet Radiation

Table 7. Safety Precautions against Health Risks of UVR Exposure

Source	Potential for Overexposure	Hazard Description	Safety Precautions
Open arcs (e.g. electric welding)	Very high	Welding arcs can exceed the UV radiation guidelines in seconds within a few meters of the arc. Workers, bystanders and passers-by can be overexposed to UVR from the arcs if engineering controls are not adequate.	Engineering and administrative controls, Personal Protective Equipment (PPE) and training.
Germicidal lamps for sterilization and disinfection	High	UVC emitting lamps used to sterilize work areas in hospitals, food industry and laboratories	Engineering controls, PPE and training
Photocuring, photohardening and etching	Medium	UV lamps are usually inside cabinets, but substantial hazardous UV radiation emitted through openings can exceed the UV guideline in seconds.	Administrative and engineering controls and training.
“Black lights” used in non destructive testing (NDT)	Medium to low	UVA lamps used in non-destructive testing in banking, commerce, materials inspection, and entertainment. “Black lights” used for insect control and entertainment are usually below exposure limits.	Engineering control and PPE for higher power (arc) lamps used in NDT. No precautions needed for insect control and entertainment lamps.
Phototherapy lamps	High	UVR used in dermatological applications generally exceed exposure limits for the patients. Medical personnel must be protected from UVR exposure.	Administrative and engineering controls , PPE and training.
UV Lasers	High	Sources of intense UV radiation at a single wavelength. Both the direct beam and stray light can exceed the UV exposure limits in a few seconds.	Administrative and engineering controls, PPE and training
Sunlamps or Tanning lamps	High to medium	Most tanning lamps emit mostly UVA radiation but modern lamps may also emit UVB. Tanning lamps generally must exceed occupational exposure limits in order to cause tanning.	PPE (eye protection) and training.
General lighting	Low	Most lamps used for lighting are made to emit little or no UVR. When UVR is emitted such as in high intensity discharge lamps, the UVR is absorbed by the envelope or covering of the lamp. If the protective envelope is broken, overexposure can occur.	No precautions needed under normal conditions. Caution should be taken if protective envelope is broken or cracked.

* The actual potential for overexposure for a given source strongly depends on exposure distance and exposure duration. Please note that this table is intended as guidance only and is not comprehensive.

5.3.1 Welding

Welding equipment falls into two broad categories; gas welding and electric arc welding. Only arc welding produces hazardous levels of UV radiation, the quality and quantity of which depend primarily on the arc current, shielding gas and the metals being welded. For example, aluminium welding produces much more UVR than the arc welding of steel for the same arc current.

Welders are the largest single occupational group exposed to hazardous artificial sources of UVR. It has been estimated that there may be half a million welders in the USA alone. UVR irradiance levels from welding arcs - and any open-arc processes - are generally very high and the permissible exposure duration before exceeding the ICNIRP guidelines is less than minute. Thus, it is not surprising that most welders at some time or other have experienced *welder's flash* (photokeratoconjunctivitis) and erythema. A survey of electric arc welders in Denmark (Eriksen 1987) showed that 65% of those questioned had experienced erythema, although no indication of the frequency was reported.

Studies of worker exposure from welding arcs have shown that the exposure at the outer clothing surface of welders can exceed daily occupational exposure limits to the unprotected eye and skin by several thousand-fold, and in some cases the UV levels on the inner surface of welders' helmets are such that additional eye protection has been advised (Tenkate & Collins 1997, Hietanen & von Nandelstadh 1998). Even ambient UV levels in the non-welding areas of factories where welding equipment is used can exceed occupational exposure limits within several minutes or hours. Therefore, not only the welder needs to be protected but also helpers (by personal protective equipment) and non-involved staff in the surrounding of the welding workplace (by appropriate shielding of the welding work place). Also care needs to be taken when there are other welding arcs in the vicinity. Welders flash may occur from adjacent arcs when a face shield is temporarily not in place, for instance while inspecting the weld or manipulating the work-piece (see also Chapter 10).

5.3.2 Sterilization and disinfection

The germicidal property of UVR has been exploited for more than a century. UVC in the wavelength range of 260-265 nm is the most effective for inactivating viruses and most bacteria, since this is the spectral region of maximum absorption by DNA. Low-pressure, mercury-discharge lamps are often the UVC radiation source of choice, since more than 90% of the radiated energy is in the 254-nm emission line. These lamps are therefore generally referred to as *germicidal lamps*, *bactericidal lamps*, or simply *UVC lamps*.

UVC is used for upper-air room disinfection in areas where the transfer of tuberculosis is of particular concern, as in prisons and in some hospitals (CIE 2003). In these applications, the lamp fixtures must be carefully installed to assure that the UVC irradiates only the volume of room air above eye level, since UVC radiation is particularly injurious to the eyes. Housing germicidal lamps behind metal barriers, normal glass or plastic provides adequate protection to workers. Exposure at short distances to bare lamps exceeds the exposure limit for the eye and the skin in only a few seconds. If the lamp is fixed in a high enough position, the exposure level at the workplace might be below the exposure limit. In some applications, lamps are used during the night when nobody occupies the room, and motion detectors can be used to switch off the lamp if somebody enters the room. UV sources are also used in the food industry to disinfect containers, tools, and work areas.

In recent years, the largest use of UVC lamps has been to disinfect sewage effluents, drinking water, water for the cosmetics industry and swimming pools. The combination of UV radiation and ozone has a very powerful oxidizing action and is capable of reducing the organic content of water to extremely low levels. Germicidal lamps are sometimes used inside microbiological safety cabinets to inactivate airborne and surface micro-organisms as well as in vacated operating theatres overnight. UVC lamps have been used since the 1930s to decrease the levels of airborne bacteria in operating theatres during surgery, but the technique is not widely used, because of the necessity to protect the eyes and skin of personnel and patient; filtered air units with UVC lamps are currently preferred. Workers maintaining UVC lamp systems require proper training to avoid accidental exposure, and clear face shields with protective clothing are required if work during UVC emission is possible.

5.3.3 Photocuring and hardening

Many industrial processes, such as the curing of lacquers, inks, glues and sealants, employ UV photochemical hardening (“drying”), and this is termed UV photocuring. Hardening of glues and plastics is often performed with UVA sources, where the exposure is relatively low. However, for special applications, sources that also emit UVB and UVC radiation are used. These processes often necessitate the use of high-power (several kilowatts) lamps, such as high-pressure metal-halide lamps. Whilst these high power lamps can emit very high levels of UVR, the industrial process is generally housed in interlocked assemblies and behind opaque baffles to prevent hazardous exposure to personnel under normal use. Maintenance procedures must be designed to assure resetting of interlocks prior to restarting the equipment after lamp exchange and servicing.

Traditionally, UVA has been used extensively in photocuring of dental resins in reconstruction of teeth. However, this has been recently replaced by visible blue light sources.

5.3.4 Banking and commerce

Signature verification is commonly performed by exposing a signature, obtained previously with colorless ink, to UVA radiation under which it fluoresces. Also, fluorescent features of banknotes can be checked with UVA lamps, and recently with UV LEDs, and these methods are often used by cashiers in stores. The electrical power of the lamps is normally no more than a few Watts and exposure time is short. Also often the lamps are shielded from direct line of sight. In normal use, no occupational UVR hazard to the eye or the skin results.

5.3.5 Entertainment facilities

UVA “blacklight” lamps are frequently used in discotheques, theatres, bars and other entertainment facilities to induce visible fluorescence in clothing, posters, and other fluorescent materials. Whilst the UVA levels are normally well below 10 W m^{-2} and would not normally present eye or skin hazards from the occasional direct exposure, UVC lamps installed inadvertently have led to severe photokeratitis.

5.3.6 Materials inspection

UVA radiation is used in materials inspection by inducing fluorescence. For instance, fluorescent liquid is applied and will remain in cracks of metal pieces which become visible upon irradiation with UVA radiation. High power sources for metal crack inspection (which often include filtered metal halide lamps) can exceed both the exposure limit of the skin and the eye for typical workplaces. In such cases, the hands can be protected by wearing of gloves, and the eye can usually be protected by shielding against a direct line of sight to the lamp – diffuse reflection should be evaluated for the specific application. Other applications where UVA induces fluorescence are inspection of fabric. UVR emissions of these lower power sources are usually below the exposure limits for typical exposure distances and durations.

5.3.7 Phototherapy

UVR is widely used in dermatological treatment facilities, and many phototherapy lamps emit high levels of UVR, usually in the UVA range with a varying degree of UVB or pure UVB. While exposure cabinets used for treatment of skin diseases minimize exposure of attendants, there is a marked UVR exposure risk to staff when the lamps are unenclosed. For example, in case of unenclosed Alpine sunlamp (“hot quartz” lamp), the recommended exposure limit can be exceeded in less than 2 minutes at a distance of 1 m. A study of hospital phototherapy staff showed that the annual UV exposure led to estimated annual occupational UV exposures ranging from approximately 30 to 400 SED per year (Diffey 1989). When the output levels of the lamps are checked with handheld power monitors by nurses or doctors (especially of higher power lamps in cabinets), personal protective equipment of the eyes and the skin is necessary.

5.3.8 Research laboratories

Many scientists engaged in photobiology, photochemistry or laser materials processing use various sources of UVR. These applications, in which the effect of UV irradiation on the biological or chemical species is of primary interest to the researcher, can be differentiated from UV fluorescence or absorption techniques where the effect is of secondary importance. Many of these sources are associated with severe UVR hazards.

5.3.9 Ultraviolet photography

There are two distinct forms of UV photography: reflected or transmitted UV photography; and UV induced fluorescence photography. In most applications the effective radiation lies within the UVA spectral band and it is unusual for human exposure to exceed occupational limits.

5.3.10 Printing industry and electronic industry

Arc lamps, UV lasers and LEDs and fluorescent UV sources are used in electronic printers and for photocuring of inks in the printing industry. Modern equipment normally is designed to completely enclose these sources; however, during maintenance and service potentially hazardous UV exposures may take place.

5.3.11 *Insect traps*

Since UVA radiation (particularly around 350 nm) attracts many flying insects, electronic insect traps employ this phenomenon. A UVA lamp is typically mounted behind a high-voltage grid, and insects attracted by the UVA lamps fly into the unit and are electrocuted in the air gap between the high-voltage grid and a grounded metal screen. Units such as these are commonly found in areas where food is prepared and sold to the public, but under normal use both occupational and public UVR exposure is very low and poses no hazard.

5.3.12 *Sunlamps and sunbeds*

In many countries UV sunlamps are popular for cosmetic tanning. Exposure to sunlamps may occur also in shops where the public can purchase sunbeds for home use. Some shops may have tens of UVA tanning appliances all switched on exposing staff to significant levels of UV radiation. When the sunbeds are located behind curtains or in cabins, UVR transmission through curtains and reflections from ceilings are usually below exposure limits in the vicinity of the cabins.

5.3.13 *Floodlighting in studios and on stage*

High power tungsten halogen and metal halide lamps are used for spotlighting for instance in television studios and on theatre stages. In some working situations (such as for news readers), staff can be exposed to levels of UVR exceeding exposure limits for the eye and skin (Hietanen and Hoikkala 1990). Since it is not possible to use personal protective equipment such as eye protection, the lamps need to be equipped with UV absorbing filters. Also, service personnel manipulating in the vicinity of the lamps need to be trained and may have to use personal protective equipment.

5.3.14 *General lighting*

Fluorescent lamps used for general lighting in offices, homes and factories emit small quantities of both UVA and UVB. For typical levels of illuminance of 500 lux from bare fluorescent lamps, UVA irradiance is about 30 mW m^{-2} and UVB irradiance about 3 mW m^{-2} , leading to an annual exposure of no more than 10 SED to indoor workers. The UVB emission can, however, vary greatly, depending upon the impurities in the glass envelope. With efforts to reduce some trace metals in the glass, high UVB levels have been measured, and annual doses of 40 SED were estimated for an illuminance level of 500 lux. These findings in part led to photobiological safety standards for lamps and lighting equipment (CIE 2002), where the effective ICNIRP UVR irradiance of “exempt” fluorescent lamps (see 7.3) has to be below $0.1 \text{ } \mu\text{W cm}^{-2}$ (1 mW m^{-2}).

Early types of desk-top lamps which incorporate tungsten halogen lamps may emit levels of UV radiation which resulted in exposure to the hands and arms of a person using the lamps in excess of recommended occupational exposure levels. However, modern type lamps feature UV blocking envelopes and exposure is well below the UVR exposure limits.

High intensity discharge (HID) mercury lamps and HID mercury fluorescent lamps are used for roadway lighting, high bay lighting and for lighting of construction sites. UVR is usually absorbed by the outer envelope of the lamp but if that envelope is broken, the internal UV

discharge lamp may continue to operate and severe over exposure of the eye and skin can occur. Normally roadway lamps are enclosed in impact resistant covers (polycarbonate) which totally absorb any hazardous short-wavelength UVR. Workers who replace lamps in high bay areas such as sporting halls, air craft hangers and large industrial buildings must be trained to identify damage lamps and their safe replacement.

6. Health Risk Assessment from Human Studies

6.1 Skin Cancer Studies

A number of studies of the quantitative risk of skin cancers (Gallagher 1985, 2005) in outdoor workers have been carried out in recent decades.

There is strong evidence from numerous epidemiological sources that excessive cumulative exposure to solar radiation causes squamous cell cancer of the skin (SCC) and lip cancer (AGNIR 2002). There is also evidence that sun exposure is related to the risk of basal cell carcinoma (BCC), although the pattern of exposure that is responsible is less clear; there is evidence that intermittent recreation exposure may be important as well as evidence for an effect of cumulative exposure. Traditionally, non-melanoma skin cancer (NMSC) has been considered a tumor typically seen in elderly, male farmers, but in epidemiological data although some routine studies show non-melanoma skin cancer to be more common in outdoor than indoor workers, this has not always been found. A possible explanation comes from a study of SCC and BCC in Queensland (Green et al 1990), in which it was found that people with fair or medium complexions and with a tendency to sunburn are under-represented amongst outdoor workers, suggesting that there may be self-selection of sun-tolerant individuals (i.e. people with low risk of NMSC) to become and remain outdoor workers. Furthermore, this study found that outdoor workers were more likely than others to wear sunhats, raising the possibility that they employ more sun protection, on average, than other individuals. Thus, although there is good evidence that excessive outdoor sun exposure over long periods will increase the risk of NMSC, it is not necessarily the case that outdoor workers are those with the highest risks of these tumors. Cutaneous malignant melanomas (CMMs) are responsible for 80% of skin cancer deaths (WHO 2003) even though CMMs represent only 5% of the skin cancer cases. Solar exposure is an important aetiology of cutaneous melanoma although the causal solar exposure patterns are less clear. Both intermittent recreational exposure of untanned skin and cumulative exposures are aetiological factors for cutaneous melanoma.

As for indoor workers, analyses of data from large studies have generally found greater risk of melanoma in indoor than outdoor occupations (according with the intermittent exposure hypothesis of aetiology), although the reverse has been found for head and neck melanoma. In individual-based studies, results on outdoor versus indoor workers have been less consistent. The evidence of the causal role of UVR in melanoma has been recently strengthened by studies of subjects who routinely engage in artificial UVR tanning. (Swerdlow and Weinstock 1998, Veierod et al 2003, Gallagher et al 2005).

6.2 Ocular Disease Studies

Epidemiological studies of the relationship between UV exposure and several age-related ocular diseases, such as pterygium, cataract, pinguecula, droplet keratopathies and ocular melanoma, have been carried out by several research groups. The quantitative risks associated with these studies have been reported only in a limited number of studies.

Chronic UV exposure is related to pterygium, droplet keratopathies, and probably pinguecula (AGNIR 2002), and there is conflicting evidence on whether age-related maculopathy is caused.

Cross-sectional studies have shown an association between chronic high levels of outdoor UV exposure and risk of cortical cataract (Cruickshanks et al 1992, Taylor et al 1988, Sasaki 2002), including one study of Watermen in Chesapeake Bay specifically focusing on occupational exposure (Taylor 1988). In clinic-based case-control studies, a significant relation of cortical cataract to occupational sun exposure (as a dichotomized variable) was found in Italy (Italian-American Cataract Study Group 1991), but not Massachusetts (Leske et al 1991).

Case-control studies have shown raised risk of ocular melanoma in subjects with light complexion (eye color, hair color, skin color), with iris freckling and naevi, and with many cutaneous naevi (Gallagher et al 1985, Holly et al 1990, Horn et al 1994, Seddon et al 1990, Tucker et al 1985). These studies have not given consistent evidence for an effect of solar UV exposure on ocular melanoma risk, but have given limited but not conclusive support to a relation to exposure to artificial UV sources – sunlamps and arc welding.

7. Occupational exposure limits and safety standards

Occupational health and safety guidelines, regulations and standards have been developed in several countries and by international organizations to protect workers and the general public from potentially hazardous exposure to UVR. Philosophical differences in the level of protection have led to some difficulties in the development of a consensus for exposure limits, since there are some who argue that UVR exposure offers more health benefit than the risks associated with skin cancer. The variability of the susceptibility to skin cancer by individuals with different skin types poses a challenge in establishing an exposure guideline for all. The two most widely used guidelines are virtually identical. Both the International Commission on Non-Ionizing Radiation Protection (ICNIRP 2004) and the American Conference of Governmental Industrial Hygienists (ACGIH 2004) guidelines for human exposure are based upon an envelope action spectrum that considers both ocular and skin effects. Although these guidelines were initially based on preventing any acute, detectable changes in corneal and epithelial cells (acute effects), they have also been analyzed to show that the risk is extremely small, or undetectable, for delayed effects in both eye and skin for persons exposed below these recommended limits. The limits are considered ceiling values for the eye, but can obviously be exceeded for the skin – at least for most skin phototypes (ICNIRP 2004).

The ICNIRP guidelines for human exposure of the eye and skin to UVR is 30 J m^{-2} - effective (i.e. 3 mJ/cm^2 -effective), when the spectral irradiance E_λ at the eye or skin surface is mathematically weighted against the hazard sensitivity spectrum $S(\lambda)$ from 180 nm to 400 nm as follows:

$$E_{eff} = \sum E_{\lambda} S(\lambda) \Delta\lambda \quad [1]$$

where

E_{eff} = effective irradiance in $\mu\text{W cm}^{-2}$ or W m^{-2}

E_{λ} = spectral irradiance in $\mu\text{W cm}^{-2} \text{ nm}^{-1}$ or $\text{W m}^{-2} \text{ nm}^{-1}$

$S(\lambda)$ = relative spectral effectiveness (unitless) - See Appendix F

$\Delta\lambda$ = bandwidth in nanometers of the calculation or measurement intervals

If the irradiance level is constant, the permissible exposure duration, t_{max} , in seconds, to the spectrally weighted UVR is calculated by:

$$t_{max} (s) = (30 \text{ J m}^{-2}) / E_{eff} (\text{W m}^{-2}) \quad [2]$$

In addition to the above requirement, following the ICNIRP guidelines, the ocular exposure is also limited to unweighted radiant exposure of $10\,000 \text{ J m}^{-2}$ (i.e., 1 J cm^{-2}) for periods up to 30 000 s (i.e. 8 h workday). That is, any exposure that has a dominant contribution from UVA needs to be evaluated against both the limits of UVA and the spectrally weighted UVR (weighted with $S(\lambda)$). It depends on the spectral distribution which one of the two exposure limits is the more restrictive one.

For the UVA requirement, the irradiance, E_{uva} in the UVA spectral region is summed from 315 nm to 400 nm:

$$E_{uva} = \sum E_{\lambda} \Delta\lambda \quad [3]$$

For constant irradiance levels, the maximum duration of exposure related to the UVA limit can be expressed as:

$$t_{max} (s) = (10\,000 \text{ J m}^{-2}) / E_{uva} (\text{W m}^{-2}) \quad [4]$$

NOTE: It is of interest that ACGIH applies the UVA limit expressed as a total radiant exposure only up to 1000 s (16.7 min), and limits the total irradiance to 10 W m^{-2} (1 mW cm^{-2}) for periods greater than 1000 s. It follows that for continuous 8 h exposure, the radiant exposure limit of $10\,000 \text{ J m}^{-2}$ is equivalent to 10 W m^{-2} following the ACGIH guidelines and to 0.3 W m^{-2} following ICNIRP. The more conservative ICNIRP guideline reflects a concern for potential photochemical effects in the lens for lengthy exposures while the ACGIH guideline was primarily set to preclude thermal effects.

The complete ICNIRP Guidelines with rationale are downloadable under www.icnirp.org/pubOptical.htm.

7.1 Application of the ICNIRP Limit for the Skin

In terms of acute skin effects from solar exposure, the limit of 30 J m^{-2} (to be compared to effective exposure levels weighted with the $S(\lambda)$ action spectrum) is equivalent to approximately 1.0 – 1.3 SED (i.e. approximately one-half of an MED for fair skin) where the exposure level that is compared to the SED is weighted with the CIE erythral effectiveness curve (CIE 2003). For a germicidal lamp, the exposure guideline is approximately equivalent to 10 SED. At this level, detectable molecular damage appears to be fully repaired. For the case of continuous exposure for longer than 8 hours, such as is possible for a 10 -12 hours extended shift (or even a double shift) for indoor workers, special care needs to be taken. The additive effects of UVR exposures greater than 8 hours are compensated for by molecular and cellular repair so that the 8 hour limit can apply for extended work periods. However, the exposure guideline is based on a normal 24 hours light/dark cycle where cellular repair can take place after the exposure is discontinued.

7.2 Application of the ICNIRP Limit for the Eye

The human eye is naturally protected by geometric characteristics from overhead exposure to solar UVR in the outdoor environment as shown in Figure 7. Therefore, the eye is much less susceptible to UV irradiation from overhead sources in the indoor environment, but very susceptible to UVR from sources directly within the normal field-of-view. For example, welding arcs and laboratory UV lamps may very well be within a line-of-sight, leading to a direct exposure of the cornea. Furthermore, high levels of UVR in sunlight are associated with very bright environments which lead to pupillary constriction and squinting that reduce ocular exposure, but lamp sources (e.g., low-pressure-mercury germicidal lamps) may have relatively low levels of visible light that would permit direct observation for extended periods. These factors must be taken into account when assessing UVR exposure hazards to the eye in indoor work environments, and the ICNIRP guidelines specify limited angular acceptance for such assessments. In both indoor and outdoor environments it would be inappropriate to use horizontal UVR irradiance to assess risk. See paragraph 8.9 for appropriate applications of the guidelines in outdoor environments.

7.3 Geometrical Aspects of the Exposure Guidelines

For the measurement of exposure levels to be compared to the exposure limits, the aperture diameter and the field of view (FOV) of the detector can have an influence on the exposure level which is measured. Except for laser exposure, highly localized exposure is generally not encountered. The ICNIRP UV guidelines (ICNIRP 2004) specify that in no case is the irradiance to be averaged over an area greater than 1 mm for pulsed sources or 3.5 mm for continuous exposure (as specified in the laser guideline (ICNIRP 2000)). For typical industrial exposures of the skin, larger averaging apertures can be used. Since the directional sensitivity of the human skin, which is assumed to be a plane surface, follows a cosine dependence, a detector is required which features a good cosine response is required even up to larger angles off the normal. However, this is relevant only for sources which are extended, i.e. non-point sources. For the eye hazard assessment, the detector field of view (or “acceptance” angle) can be reduced and limited to $80^\circ (\pm 40^\circ \text{ from the normal})$. See Section 8 for measurement guidance.

7.4 CIE Risk Groups for Lamps

The International Commission on Illumination (CIE) has produced a technical standard for lamps and lamp systems in order to indicate the potential photobiological risk posed by the lamp. The standard was developed as a manufacturer's standard to specify risk groups, which are supposed to be assigned to the lamp by the manufacturer.

The Risk Group definitions are based on varying maximum permissible exposure durations, so that for the exempt group, effective exposure at the reference distance (for specialized UV lamps 20 cm) to the lamp is below the UVR exposure limit for the eye for 8 hours. For Risk Group 3, the UVR exposure limit at 20 cm is exceeded in times shorter than 1000 s (about 16 minutes). Lamp Risk Groups are not only based on the UVR limit, but on all relevant exposure limits, as shown in Table 8, where also the respective safe exposure durations at the reference distance is listed. In that sense, the CIE lamp safety standard is related to the emission of the source rather than characterizing the exposure of a person which depends on the actual distance and exposure duration.

Table 8. CIE lamp risk groups

	Exempt	Risk Group 1	Risk Group 2	Risk Group 3
	<i>No Hazard</i>	<i>Low-Risk</i>	<i>Moderate Risk</i>	<i>High-Risk</i>
<i>Type of Hazard</i>	Exposure limit not exceeded for exposure durations up to: (i.e. exceeded for exposure durations beyond:)			Exposure limit exceeded within:
<i>Actinic UV (skin and eye)</i>	30 000 s	10000 s	1000 s	< 1000 s
<i>UVA (Lens)</i>	1000 s (~ 16 min)	300 s	100 s	< 100 s
<i>Photochemical (retina)</i>	10000 s (~ 2.8 h)	100 s	0.25 s (natural aversion)	< 0.25 s
<i>Thermal (retina)</i>	10 s	10 s	0.25 s (natural aversion)	< 0.25 s
<i>Infrared (cornea, lens)</i>	1000 s	100 s	10 s	< 10 s

NOTE: It should be noted that the CIE exempt group regarding the un-weighted UVA limit was based on the ACGIH integration duration of 1000 s and exposure to such lamps from a distance of 20 cm for longer than 16 minutes might lead to exposures above the limit as recommended by ICNIRP, where the integration duration is 8 hours.

Two different distances of measurement are defined in the standard for the risk group classification depending on the intended use: the distance where the illuminance level equals 500 lux for general lighting service lamps and 20 cm for non-general lighting service lamp. Most lamps that emit a relevant amount of UVR are non-general lighting sources.

The risk group classification following the CIE standard provides useful information to facilitate the hazard analysis of a certain lamp. For lamps that are in the exempt group, no further hazard analysis is necessary except in extreme cases of short distances and long term exposure to UVA lamps. However, it should be noted that the risk group determination is based on measurements at 20 cm, which for many practical applications is not realistic. For greater distances, the risk is reduced in the sense that allowed exposure durations correspondingly increase with distance.

8. Exposure Assessment

8.1 Introduction

The measurement or monitoring of UVR from artificial sources or from sunlight may be required for assessment of the worker's exposure. There is a range of instruments of varying sophistication available and the choice of a particular instrument will depend upon the accuracy and/or ease to which measurements are required. National networks to measure the solar UVR have been established and some provide data to the public in the form of the Global Solar UV Index (UVI) on a daily basis. Knowledge of the UVI can help to choose the level of protective measures for outdoor workers. For example certain protective measures such as hats may be keyed to UVI values above 5 in some locations.

Measurements are not always required when source information or calculations are sufficient for providing the basis for exposure evaluation. A number of approaches have been developed. For example, UV sources can be grouped into different risk categories (as provided by the manufacturer), such as those developed by the CIE for lamp risk groups (CIE 2002), and protective measures (engineering and/or personal protective measures) would be keyed to the risk group. An "exempt" category of sources would require no further hazard assessment or protective measures, and the protective measures for Risk-Group 1 would only be necessary for prolonged exposures. A number of publications provide typical UV emission characteristics of commercial UVR sources (McKinley et al 1988, Sliney and Wolbarsht 1980). Detailed measurements would then only be required when the exposure is at or near exposure limits. If the exposure is clearly very low and well below limits, no action would be required. If the source of UVR can be encapsulated (shielded) so that no exposure occurs outside the encapsulation or shielding, an exposure assessment is also not needed. If the exposures are clearly far above the occupational exposure limits, as in many welding operations, strict protective measures will be required. In this case, an exact determination of exposure may not be required for the welder or an associate (helper) when properly protected; however, measurements may be necessary for other unprotected persons further away from the source.

8.2 Measurement Aims

Measurements are most likely to be of value when assessing indoor exposures to UV sources where the characteristics of the sources are generally fixed and work practices are repetitive. On the other hand, the constantly changing position of the sun with time of day and season and changing meteorological conditions limits the usefulness of site-specific measurements for predictive risk assessment in most outdoor occupations. However, they may be used to demonstrate current exposure conditions to workers and the need for protection.

Examples of need for measurements are as follows:

8.2.1 Measurement of indoor workers' exposure

If a worker is exposed to potentially hazardous levels of UVR at the workplace, adequate protective measures are necessary. There may be a value in characterizing the exposure level through calculations or measurements. The measurement result is compared with the exposure

limit value. When the exposure limit is exceeded, protective measures such as shielding of the source or the use of personal protection have to be applied.

When carrying out such evaluations it is frequently possible to reduce or eliminate some measurements by estimating worst-case exposures. This may be possible from manufacturer's data or a single emission measurement at the source. If, by choosing the maximum value, the result does not exceed the exposure limit, no further assessment is required. However, care has to be taken when analyzing a source for a specific work task. Unlike some workplace exposures, the UV exposure level can vary drastically depending on the behavior of the worker. For instance for welding, the UV emission can strongly vary with the welding process and materials used.

8.2.2 Measurement for consultations concerning an accident or a disease

If an accident has occurred or a disease has developed in an indoor worker, often an expert consultation is needed. The expert has to assess if there is a connection between the workers exposure and the accident or the disease. If measurements are needed, it is frequently not possible to reduce the measurement expenditure by choosing maximum values for unknown parameters. All parameters need to be determined as exactly as possible, even if it may be very difficult.

8.2.3 Other measurement aims

In addition to work-site measurements, laboratory measurements may be made for the purpose of:

- Determination of the emission and spectrum of a radiation source (for example to determine the Risk Group of the lamp)
- Determination of the attenuation effect of a radiation screen, barrier or filter including eye protection
- Determination of reflective characteristics of some building materials

8.3 Measurement Devices

Depending on the quantity that is to be measured and the required accuracy, different measurement techniques and equipment can be used.

There are two aspects which are relevant for safety related measurements of UV radiation and they are accounted for in the different measurement devices in different ways: the summation (integration) over the spectral range including some weighting with an action spectrum and the summation (integration) of the exposure time.

8.3.1 Geometrical characteristics

As noted in the presentation of the exposure limits (Appendix A and Section 8.5), the geometrical characteristics to include measurement aperture, angular response and the field of

view may be important, depending upon the source to be measured. The size of the measurement aperture is important if the irradiation field is highly non-homogenous, and the angular response and the field of view are important (they are also different for eye and skin hazard evaluation) if the source is very large.

8.3.2 Spectroradiometers

Spectroradiometry is the technique for measuring the spectral irradiance (measurement showing spectral shape and power) that is produced by a source of optical radiation at a given position relative to the source. The three basic features of a spectrometer system are the input optics, designed to conduct the radiation from the source into the monochromator, which disperses the radiation onto a detector. For accurate measurements of UVR, it is necessary to use a double monochromator. Single monochromators may suffer from stray light problems which result in erroneous measurement. Particularly problematic is the use of diode arrays to measure UVR. Double monochromators are expensive instruments but are the most accurate and precise tools. They are not needed for routine safety surveys and monitoring, but rather in laboratories for lamp risk group determination or for research projects or experts assessments on work place safety.

8.3.3 Broad-band UV radiometers

For practical hazard evaluations, broad-band integrating UV safety meters with detectors that mimic the ICNIRP UV-hazard action spectra are the most useful instruments. These safety meters basically consist of a photodetector with spectral filters and an electronic readout unit. They are generally calibrated to read directly in effective UV irradiance or in effective radiant exposure. Some even indicate maximal permissible exposure duration $t_{\max}$. Achieving a detector that truly responds to the required action spectrum such as $S(\lambda)$ or to only be sensitive to the UVA in an unweighted fashion is very difficult. Consequently, the detector can only approximate the required action spectrum and the measured effective value can in some cases (depending on the quality of the meter and on the spectral distribution of the source) be seriously erroneous. The detector can be calibrated more accurately for a few representative sources such as xenon arcs, germicidal lamps or tungsten-halogen lamps. Similar instruments originally designed as erythral biometers that follow the spectral response of the CIE erythral effectiveness curve also respond mainly to UVB/C radiation with a variable response in the UVA. These can be calibrated with some degree of accuracy for a few representative sources in terms of ICNIRP effective irradiance. However, UV meters designed to mimic action spectra for germicidal applications or photocuring applications will generally have such strongly different spectral response that they would not be useful for hazard evaluation.

In terms of the geometrical sensitivity of the detector, most instrument manufacturers aim to achieve a cosine receptor response, which is desirable for assessing skin exposure from extended sources. However, for assessment of eye exposure, a field of view attachment fulfilling the measurement criteria in the guideline of $\pm 40^\circ$ is useful (and for the measurement, the detector should be aimed along the line-of-sight of the eyes and not upward toward sources that are not constantly viewed). An “open” field of view would overestimate the exposure value.

8.3.4 Personal dosimeters

In recent years, broad-band safety meters became available which are small enough to be used as personal dosimeters, i.e. fixed to a person's clothing or hat and worn during the workday. These personal safety meters either add up the dose continuously or record the time varying irradiance to be read out after the working day. They may even provide audible warning or flashing lights to cease exposure. Some are designed specifically for protecting against overexposure to solar UVR (often in the shape of wrist bands or lapels) mimicking the CIE erythral effectiveness curve and some may require the input of skin sensitivity. The accuracy and the price vary widely for broad-band safety meters, mainly depending on the quality of the spectral responsivity of the detector.

Besides electronic instruments, a number of film dosimeters have been developed. These are based on photo-induced changes of chemical or biological materials. The magnitude of the change is related to the effective UVR dose. They accumulate the effect over a certain time and are subsequently analyzed in a laboratory. Since the level of exposure is determined with some delay, they can not be used as a direct warning device against overexposure. These dosimeters may be used for occupational safety assessments where the exposure level is assessed for a specific source and task to decide on the need for protective measures or more accurate assessment. The advantage when compared to electronic instruments is that they are very light and can be worn without impeding the worker. However, the spectral response only roughly follows erythral effectiveness curve or the ICNIRP hazard action spectrum. Film dosimeters have been most extensively optimized for solar UVR measurements weighted with the erythral effectiveness curve. For the measurement of UVR emitted by other sources, dosimeters would need to be calibrated specifically according to the spectral distribution of the source to be measured and the action spectrum to be used.

The most commonly used, reliable material for personal UV dosimetry has been the thermoplastic polysulphone. The basis of the method is that when the film is exposed to UVR at wavelengths principally in the UVB waveband, its UV absorption increases. In practice, the film (around 40 μm thick) is mounted in cardboard or plastic photographic holders. Other film dosimeters, referred to as biosensors, are based on the effect of UVR on the germination of spores. Basically, any type of measurement system can be used to evaluate personal exposure.

Ideally, personal dosimeters would have the following characteristics:

- Be easy to handle and not impose restrictions on the activities of the wearers.
- Have a linear UV dose response and be independent of dose rate.
- Have a photoadditive response, where each wavelength acts independently and the effect of polychromatic radiation is the sum of the effects of all wavelengths involved.
- Match the action spectrum of the photobiological effect being monitored $S(\lambda)$ or alternatively CIE erythral curve.
- Have a response independent of temperature and humidity.
- Exhibit no 'dark effect' (continuing response when radiation exposure terminated) and be stable in long-term storage.

- Have a simple readout process that allows easy conversion to the desired measure of UVR exposure dose.
- Have a low cost per dosimeter to permit large-scale monitoring.

8.4 Procedure of Detailed Indoor Exposure Assessment

For each exposure assessment, a detailed plan should be prepared and should consider the following:

- The target of the assessment and the basis of the assessment, e.g. the exposure limit values to be applied
- Collect available manufacturer's data on the source, filters and on possible changes made by the user (e.g. replacement lamps)
- The initial work task analysis and worst case exposure assessment
- Determine whether site measurements are necessary and what limits upon uncertainty is required
- The equipment used and the measurement procedures, or data source if calculations are used
- Make photographs or videos of the workplace and, if a more detailed work task analysis is required, the exposure situations and the measurement points
- Number of times to repeat any measurements and the exposure assessment
- All other necessary details concerning the workplace, the exposed people, the measurement operator, the date and place of the measurement, etc..

8.4.1 Work task analysis

Before initiating calculations of exposures or measurements, one should carry out a detailed work task analysis, i.e. a careful examination of all working steps of the person whose exposure is to be determined. Inquire if acute effects such as erythema, photokeratoconjunctivitis have occurred. If there are no acute effects reported, this should not be misinterpreted to preclude a potential hazard of exceeding the exposure limits. However, the occurrence of acute effects might indicate special circumstances of increased risk which might not exist during routine operations. An initial worst-case assessment (in terms of exposure duration and distance) may show that further measurements and/or calculations are not required.

For a detailed analysis, all points (distance and position relative to the source) at which the person remains during the work and the potential body sites of exposure are noted. Then, the duration of exposure at each location is determined. Record the application or non-application of protective measures, such as the use of personal protective equipment. Finally, determine the total exposure duration within a day and even during a year. Assess whether the working conditions are stable or may change in the future and thereby affect the total exposure assessment.

8.4.2 *Orientation of the detector*

For the determination of a realistic level of exposure, it is important that the detector is positioned where exposure is expected to occur. The orientation of the detector (the direction of the normal of the detector surface) also should be chosen as realistically as possible. This is especially important for the evaluation of hazards to the eye in situations where the source is overhead and outside of the field of view (such as the mid-day sun or a lamp mounted on the ceiling) since one rarely looks up to the direction of the source so that prolonged exposure can really only be caused by reflections (for instance from the ground).

8.4.3 *Output varying with time*

Often the output of the radiation is not constant but is varying with time. Examples are: welding arcs, radiation emission of photocuring devices, which vary within the duty cycle of the equipment (e.g. printing machines), etc. If the source spectrum is unknown, a portable spectrometer that measures all wavelengths at once (e.g. array detectors) could be used. However, these devices are frequently insensitive if the irradiance is very low, and serious errors from stray light can plague the measurement. Therefore, broadband instruments will normally be required. As the occupational exposure limits are specified as radiant exposure doses, the time varying effective irradiance values must be recorded to calculate the exposure dose. Some instruments can also integrate over time to provide comparison with exposure limits directly. A desirable feature in a broadband meter would be time averaging for highly fluctuating sources, such as welding arcs.

8.4.4 *Motion of the worker*

Workers often do not remain at one given distance and orientation to the source. Therefore, the time-integrated personal irradiance caused by a fixed radiation source will vary from point to point and will depend on the direction of view of the worker. A practical way of assessing the resulting total radiant exposure of a worker is to determine the effective irradiance at different distances from the source and directions of view, and estimating exposure durations for the respective distances. The local exposure dose is determined by multiplication of the irradiance level and corresponding exposure duration. The total radiant exposure is the sum of all local exposure doses.

Alternatively it may be desirable to attach a personal dosimeter to the worker. Most commercially available dosimeters do not meet all the requirements of spectral response (following the ICNIRP weighting curve), sensitivity and angular response. Another problem relates to the direction of emission from the source and from reflections if present. A moving worker will always change position in relation to the source and it may be unclear where to fix the dosimeter: on the chest, the back, a shoulder or on several anatomical sites. Thus, current dosimeters should not be relied upon as the sole source of measurement but they may provide relevant information.

8.4.5 *Moving Source*

Sometimes the UV source is moving or the radiation field is changing its direction, e.g. a moving UV spotlight beam. It may be difficult to determine an accurate cumulative exposure of people in such cases.

8.4.6 *Non-visible source radiation and reflections*

It is rare that a UVR source does not also emit at least some visible radiation and the source itself can be seen. However, one should not judge the source of radiation solely by what is visible. For example, the character of reflections within the workplace can frequently not be judged from the material characteristics in the visible spectrum. Many materials, such as most white paints are not reflective in the UV spectral region, particularly in the UVB and UVC regions. Some metals, particularly aluminium, maybe highly reflective in the ultraviolet wavelength range. For instance, reflections might become relevant if protective measures, such as face shields, do not protect against radiation from all directions.

8.4.7 *Choice of instrumentation*

In some situations where high accuracy is needed, a double-grating monochromater spectroradiometer should be used to measure the spectral irradiance at a given reference point. A broad-band radiometer would be used to determine the time or position dependent irradiance, relative to the reference point measurement.

8.5 Relevant properties of measurement systems

For the measurement of exposure levels to be compared to the exposure limits as noted in Paragraph 8.3.1, geometrical aspects of the exposure must be considered. The following properties of measurement systems are relevant for obtaining valid data to be compared to exposure limits. It is noted that the aperture diameter, field of view (FOV) (acceptance angle), and the cosine dependence of the detector are important.

8.5.1 *Irradiance averaging*

The diameter of the input aperture of the detector does not have an impact on the measurement if the irradiance profile is homogeneous. If there are hotspots in the irradiance profile, the diameter of the aperture should be small enough to resolve the hotspot, however, it is usually not necessary to use aperture diameters less than ~ 7 – 10 mm unless laser beams are being measured.

8.5.2 *Field of view (acceptance angle)*

The field of view of the detector (the “part” of the world which is seen by the detector) should be 180° for measurements to be used for skin hazard assessment and should be limited to 80° ($\pm 40^\circ$ from the normal) for measurements to be used for eye hazard assessment. The field of view for eye evaluations does not play a role if the source is smaller than the field of view of the detector.

If the source is larger than 80° and the field of view of the instrument is not limited, then the exposure level is overestimated. For skin measurements, the angular dependence of the sensitivity of the detector within the field of view should be following a cosine law (see next paragraph). Due to the difference of the field of view for measurements for skin or eye exposure, for sources which subtend an angle larger than 80° at the distance of evaluation, the exposure level which is compared to the exposure limit will be different (less for the eye than for the skin). Therefore, although the UVR exposure limit is the same, since the exposure level for a given source and exposure distance, might be different, the exposure of the eye might be below the exposure limit while the exposure of the skin might be above the exposure limit.

8.5.3 *Cosine dependence*

The dependence of the sensitivity of the detector on the angle of incidence of the radiation should follow a cosine dependence. Thus the detector mimics the directional sensitivity of the human skin, which is assumed to be a plane surface. However, this is relevant only for sources which are extended, i.e. non-point sources. The larger the source is, the more important it is that the detector features a good cosine response even up to larger angles off the normal.

8.5.4 *Spectral responsivity*

The spectral responsivity of the detector should ideally be identical to the applicable action spectrum. This is the biggest practical problem encountered with the use of UVR meters. Radiation outside of the wavelength range over which the action spectrum is defined should be rejected, i.e. not contribute to the measured value. Some UV-detectors and spectrometers are also erroneously sensitive in the visible region. As the visible radiation level of the source being measured is often much higher than the UV-level, this may severely compromise the accuracy of the measurement. Without a specific calibration of the broadband meter for the source that is to be measured, it is not recommended to use broadband meters for critical measurements such as for expert opinions.

8.5.5 *Minimum sensitivity*

The minimum sensitivity of a measurement system can be estimated by considering the exposure limit given as a radiant exposure (dose) and the expected exposure duration. The minimum sensitivity in terms of measured irradiance is calculated by dividing the exposure limit by the exposure duration. For instance, with an exposure limit of 30 J m^{-2} and an expected maximum exposure duration of 8 hours, the minimal level of irradiance which can lead to exceeding the exposure limit (and thus should be the sensitivity limit of the radiometer) is 10^{-3} W m^{-2} (1 mW m^{-2} , or $0.1 \mu\text{W cm}^{-2}$).

8.5.6 *Dynamic range*

Especially for spectroradiometers, a large dynamic range is often necessary for accurate measurements, especially when there is a weak source emission in the UVC/UVB region and a strong emission in the UVA region, as the action spectrum is dominant in the UVC/UVB and the UVA region contributes relatively little to the effective irradiance.

8.5.7 *Temporal response*

The averaging time of the measurement procedure must be adequate to deal with fluctuations of the source output. The time period of integration of the radiant exposure should be adequate to assess the time period for which the limit value is specified. However, it may be sufficient to use a shorter measurement time if the irradiance is constant or if it is varying periodically and if one can deduce an 8 hour equivalent value from the measurement result.

8.5.8 *Uncertainty*

The uncertainties of the measurement procedure (including determination of the exposure duration to determine the radiant exposure dose) must be sufficiently small so that it is possible to determine if an exposure limit has been exceeded. That is, if the exposure is far below the exposure limit, the requirements regarding for uncertainty are not very demanding and rough estimates can suffice; however, if the exposure level is close to the exposure limit, demands for a low uncertainty are high. Since the uncertainty of a broadband meter may strongly depend on the spectral distribution of the source, the information on the actual uncertainty is often not available from the manufacturer and would have to be determined by spectral measurement.

8.5.9 *Environmental conditions*

The performance requirements of the instruments must be fulfilled under the environmental conditions present at the workplace. Influences of climate (temperature, humidity, pressure, and wind), dust, gases, etc. should be considered.

8.6 Ocular Exposure from Indoor Sources

When a worker is exposed to UVR from welding arcs and similar indoor sources of UVR, the normal geometrical protection afforded by the upper lid and brow ridge are no longer effective, and the eye is particularly vulnerable. This explains why the first symptoms of welder's flash are to the cornea, which is more sensitive than the skin. However, a sensitive individual who spends too much time in summer sunlight seldom experiences photokeratitis accompanying painful sunburn.

8.7 Hazard Evaluation and Risk Assessment for Outdoor Workers

Hazard assessment for outdoor work can only be semi-quantitative. A study of the worksite and tasks can provide an indication of individual worker exposure. The role of site-specific measurements in this scheme is limited. The Global Solar UV Index available from regional sources (see 3.2.2.1) has been shown to be very useful for public health education and recreational solar risk assessment. However the UVI is of limited value for outdoor workers other than for initial training for safe outdoor work practices. While it can establish an initial baseline exposure value, emphasis on work practices is more important. Work-specific factors to consider include the following:

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- The initial work task analysis and worst-case exposure assessment including spatial and temporal factors, such as the time and duration of lunch and work breaks
- Photographs or videos of the workplace and the work carried out if a more detailed work task analysis is required.
- The aims, e.g. proposals for improving the exposure situation and the safety at work if necessary
- All other necessary details concerning the workplace, the exposed people, the engineering and administrative procedures in place and the type of hats and clothing being worn, available shade and shade structures, etc.

As noted previously, the assessment of UVR exposure for different work conditions is very difficult. Table 9 provides a set of factors that quantitatively influence the magnitude of *skin exposure* in the outdoor environment. These factors are not all strictly independent, although it is possible to make an indicative assessment if some details of work location, season, duration, environment and levels of protection are known or can be estimated. Comparable hazard assessment factors for ocular exposures are given in Table 10. These Tables list factors that can be used for the hazard assessments.

Table 9. Hazard assessment factors for skin exposure

<i>Season</i>	Geographical Latitude (Factor f_1)		
	>50°N or S	30° - 50° N or S	<30° N or S
Spring/Summer	4	7	9
Autumn/Winter	0.3	1.5	5

Cloud cover	Factor f_2
Clear sky	1
Partial cloud sometimes covering sun	0.7
Overcast sky	0.2

Duration of exposure	Factor f_3
All day	1
An hour or two around midday	0.5
Early morning or late afternoon	0.2

Ground reflectance	Factor f_4
Fresh snow	1.8
Dry sand, sea surf, concrete	1.2
All other surfaces, including open water	1

Clothing	Factor f_5
Unprotected trunk, shoulders & legs	1
Protected trunk but exposed arms & legs	0.5
Fully clothed with only hands & face exposed	0.02

Shade	Factor f_6
No shade e.g. open fields, tundra, beach, ocean	1
Partial shade e.g. low density housing, scattered trees	0.3
Good shade e.g. high density housing, forest, canopy	0.02

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Once factors have been assigned for each situation they should be multiplied together to determine the Exposure Factor as:

$$\text{Skin Exposure Factor} = f_1 f_2 f_3 f_4 f_5 f_6 \quad [5]$$

The following guide should be used to categories the exposure and to ascertain the minimal level of protection required for the workplace.

<i>Exposure Factor</i>	<i>Skin Protection Required</i>
<1	None
>1 but <3	Shirt, brimmed hat
>3 but <5	Long-sleeved shirt, trousers, brimmed hat, SPF15+ sunscreen
>5	Modify work environment & practices. Try to create some shade. Long-sleeved shirt and trousers, brimmed hat, SPF15+ sunscreen

Table 10. Hazard assessment factors for ocular exposure (adapted from Sliney 1995)

<i>Season</i>	Geographical Latitude (Factor f_1)		
	>50°N or S	30° - 50° N or S	<30° N or S
Spring/Summer	4	7	9
Autumn/Winter	0.3	1.5	5

Cloud cover	Factor f_2
Clear sky	1
Partial cloud sometimes covering sun	1.5
Overcast sky	0.8

Duration of exposure	Factor f_3
All day	1
An hour or two around midday	0.3-0.5
Four - five hours around midday	
Early morning or late afternoon	0.2

Ground reflectance	Factor f_4
Fresh snow	1.0
Dry sand, sea surf, concrete	0.1
All other surfaces, including open water	0.02

Eyewear	Factor f_5
None	1
Sunglasses without hat	0.5
Clear spectacles without brimmed hat	0.2
Sunglasses or spectacles with brimmed hat	0.02

Shade	Factor f_6
No shade e.g. open fields, tundra, beach, ocean	1
Horizon blocked by hills, housing, scattered trees	0.3
Horizon and lower sky blocked by tall buildings/terrain	0.02

Once factors have been assigned for each situation they should be multiplied together to determine the Exposure Factor as:

$$\text{Ocular Exposure Factor} = f_1 f_2 f_3 f_4 f_5 f_6 \quad [6]$$

The following guide can be used to categories the exposure and to ascertain the minimal level of protection required for the workplace.

<i>Exposure Factor</i>	<i>Ocular Protection Required</i>
<1	None
>1 but <3	Brimmed hat
>3 but <5	Brimmed hat and spectacle lenses or sunglasses
>5	Wraparound eye protection and brimmed hat

8.8 Comparison of Measured Solar Exposure and the ICNIRP Guidelines

The ICNIRP guidelines on occupational exposure to UVR has an exposure limit of 30 J m⁻² and on a horizontal surface in the summer under a clear sky condition in tropical conditions would be exceeded in 6 minutes around solar noon. Under the same conditions and using the CIE erythral spectral effectiveness function, the time to achieve one SED (100 J m⁻²) is approximately 5 minutes. At other times of the day, these durations will be longer. The result is that outdoor workers who belong to skin types 1 to 4 need to be well protected. Estimating that ambient UVR is averaging 40 SED, the body sites uncovered by clothing are receiving 10 SED per day on arms and legs for all-day exposure. The shoulders are exceptionally vulnerable to solar exposure and may be exposed to between 20 and 30 SED under the same conditions. Often, many workers do not experience sunburn, which means that they must have adapted to solar exposures, but nevertheless, that means that accumulation of significant solar UVR may have implication for the induction of skin cancer later in the life.

Initially the ACGIH guidelines recommended that the UVR TLV be considered a "ceiling value" for the eye but not for the skin. This meant at that time that one could exceed the exposure limits for the skin based upon the skin's degree of sensitivity (phototype). In any practical hazard evaluation and risk assessment today, it has become customary by many who apply the ACGIH TLV to recognize that it is a limit directly applicable to exposure of the cornea (under worst-case conditions of normal incidence), but excursions above the TLV for well-adapted skin have been considered by many not to pose a serious risk. Certainly this higher skin exposure is routinely accepted in an outdoor work environment. Some phototypes with heavy natural pigmentation certainly do not experience the same risk of either acute or chronic effects as those of Celtic origin with a sensitive skin phototype.

8.9 Outdoor Exposure Guidelines

The use of the ICNIRP exposure guideline in an outdoor setting poses many problems of adequate dose assessment. Outdoor exposure, particularly in mid-summer, routinely appears to exceed the ICNIRP exposure limit. If one calculates the permissible exposure duration ($t_{\max}$) for horizontal exposure in the prone position with the eyes directed to the sun (however unrealistic), the exposure limits may be exceeded in 5-10 minutes on a bright summer day at noon time. However under most situations, the ocular exposure does not actually exceed the limit for even greater exposure duration extending to several hours (Sloney 1986, 1983, 1995). For example, the research work which developed the thresholds for photokeratitis showed that corneal examinations of humans exposed in a desert environment for much of the day were just beginning to show the signs of threshold photokeratitis (Sloney 1983). This means that only in unusual, harsh environmental conditions would one actually exceed the TLV for exposure of the cornea. While this seems quite remarkable when one considers how easy it is for sensitive persons to experience a “sunburn” from outdoor summer exposures, a careful study of ocular exposure shows that it is greatly limited by the brow ridge, the upper lid, squinting reactions, and behavioral response to sunlight (Sloney 1986, 1995). This consideration also illustrates the problem of performing a realistic risk assessment for ocular exposure in sunlight. Ground reflectance dominates ocular exposure. As the eyes are routinely directed forward and downward in outdoor activities, the upper lids block the UVR from the sky. The radiant energy that is incident normal (perpendicularly) to the surface of the cornea comes from ground reflections. Therefore, photokeratitis only occurs when one is over snow or highly reflecting sand surfaces, which are highly reflective in the UVB spectral region. Snow blindness occurs most often in late winter, with snow still present and the sun still not very high in the sky. This illustrates the controlling factor of ground reflectance. However, there may be outdoor work tasks which involve exposure of reflecting surfaces, such as copper roofing, for an extended period of time, and for these situations, ocular exposure can exceed the UV exposure limit.

9. Protective measures for outdoor workers

For most workers, the greatest source of exposure to UVR is the Sun. For people with white skin living in the tropics (30°N to 30°S), sun protection is necessary all year, whereas for those living in temperate latitudes (40° to 60°), sun awareness is generally limited to the 6-month period centered on the summer solstice (e.g., April to September in the northern hemisphere and October to March in the southern hemisphere) when the Global Solar UV Index exceeds 3. Several methods of reducing personal exposure to solar UVR are available. Dependent upon the type of work, generic methods include:

- avoiding exposure to direct sunlight during the period around noon in spring and summer
- seeking shade
- clothing and eyewear that are designed to provide a high level of protection from UVR
- hats with broad brims that provide shade to the face and neck, preferably with neck flaps
- eye protection with wrap-around design or sunglasses with side panels
- broad-spectrum topical sunscreens with an SPF of at least 30, applied liberally.

- avoid unnecessary additional elective UV exposure, as from sunbed use.

When these measures are used properly and in combination, it is possible to reduce exposure to solar UVR to within acceptable levels without seriously limiting the range of outdoor activities that can be safely pursued. Protective measures should be adequate but consistent with the type of work being conducted and not impair the efficiency of the work or cause additional hazards. Whilst protection of the eye is essential for all races, skin protection is much more important for workers with sun-sensitive (melano-compromised) skin (Table 2). The following guidance for skin protection is therefore critical for the latter category of workers.

9.1 Engineering Controls and Shade

Shade can be provided naturally by trees, by utilizing canopies and semi-permanent structures, or by constructed shade in areas where large numbers of workers may gather. It is important that the shade structure used blocks the line-of-sight path from most of the sky, as well as that from the solar disc. At least half of the total (“global”) solar UVR is received from the sky, as a result of scattering by the atmosphere. An even greater fraction is skylight (“diffuse” component of sunlight) under cloudy or hazy conditions or when the solar zenith angle is greater. At lower latitudes, the contribution from the sky is smaller than that from the solar disc, but is never insignificant. This effect is more pronounced for UVR than visible radiation, so that observing the amount of shade provided by a structure at visible wavelengths provides an over-estimate of its UVR protective properties. Small shade structures that leave large amounts of sky visible will provide only limited UVR protection; this protection may be sufficient for those workers outdoors for 1-2 h or less. An example of practical use of shade is the addition of an awning to workers on a scaffold. Canopies or cabs on earth-moving equipment and farm tractors can provide substantial protection. Since glass strongly attenuates UVB and some shorter wavelengths of UVA, glass enclosures, windows in automobiles, trucks and the cabs of tractors and earth-moving equipment can provide substantial protection; hence, if such equipment can be operated with windows up, greater protection can be afforded. Some vehicle windows, such as windscreens have a shatter-proof laminate that contains a UVB absorber, with the result that UVA radiation is blocked as well.

Materials that are visibly clear will absorb UVR to varying degrees. For example, window glass transmits some radiation down to 310nm (within the UVB), whereas most plastics such as polymethyl-methacralite (e.g., Perspex® or Lucite®) and polycarbonate normally do not transmit below about 370 nm. In general windscreens (windshields) on cars block both UVA and UVB (Sliney 1994). Cockpit windscreens on airplanes block UVB and UVA (Diffey and Roscoe 1990).

9.2 Administrative Controls

9.2.1 Educational Programs: Training and Awareness

Training programs must be tailored to local circumstances. A program for outdoor workers in the tropics would not be appropriate for workers in more temperate zones. The nature of the

outdoor work, social customs and skin phototypes must be considered in developing educational programs.

The following aspects of a training program should be considered:

- Provide an introductory talk on UV awareness and protection advice appropriate to the job. Provide refresher briefings as appropriate, such as when moving to a new work site.
- Supervisory personnel to receive training on the UVR risks to outdoor workers and the appropriate protective measures.
- Fact sheets made available for the outdoor worker on UV exposure risks and safe practice. These can be located in briefing rooms and in modes of transport to the work site.
- Training in the application of added control measures varying with increasing values of the Global Solar UV Index (UVI) can be useful. Posting the UVI at the worksite with elementary precautions can maintain worker awareness.

Cultural attitudes toward sunlight exposure, perceptions of the “benefits” of tanning and any discomfort or inconvenience related to protective measures will mitigate against successful implementation of UVR protective advice. Therefore, to be successful, educational programs aimed at changing entrenched behavioral attitudes will be required and should be designed and implemented by professionals. A special educational campaign can be effective, but must be carefully planned (Dutch Cancer Society 1996).

9.2.2 Recognizing Individual Susceptibilities

The widespread variation in the susceptibility of the individual depending on the different phototypes poses special challenges for general worker training programs. The workers should be informed of their phototype and the risk implications to their work in a hazardous UVR environment. For example, a phototype 1 or 2 individual (melano-compromised) working on an oil platform in the tropics should be fully advised of the increased risk working in the high solar UVR environment and of appropriate protective measures. Some workers may determine that they should seek employment in a less hazardous environment.

9.2.3 Simple Tips for Sun Avoidance

Because of the difficulty for an individual to estimate the relative UVR risk on a particular day, the Global Solar UV Index (UVI) was developed as a communication tool (WHO, WMO, UNEP, and ICNIRP, 2002). Health authorities, weather bureaus, and management can exploit the UVI to communicate the level of ambient solar UVR and risk to the outdoor workers.

Easy-to-follow guidance to the worker on how to effectively reduce exposure is essential. As an example of a simple assessment of risk, whenever someone's shadow is shorter than their height, care should be taken. The shorter the shadow, the stronger are the sun's UV rays and the more likely is sunburn to occur.

Under clear skies during summer months, the highest levels of solar UVR are received around noon. Consideration should be given to this issue when planning outdoor work tasks and public

events, as well as for personal activities. Under variable cloud conditions in summer months, breaks in the cloud cover can allow the increase of UVR to levels similar to (or even greater than) clear sky conditions and can add significantly to the daily UVR dose.

Sunburn can occur on cloudy days as well as clear days, although heavy, overcast skies do offer some protection. It is the ultraviolet rays, and not the infrared rays, of the sun that are harmful so a cool, windy day will not necessarily prevent sunburn.

Sun safety is also important during leisure hours. Care should be exercised in and around water in open spaces. Many people get sunburnt when they are swimming, boating or playing on a beach.

9.2.4 *Work Hours*

Outdoor work during the four-hour midday period results in the greatest risk from UVR and should be avoided where possible. Lunch and rest periods are best taken in the shade. Social customs in many tropical countries have favored extended midday breaks (siestas and lunch) indoors. However, despite the merit of such practices, these may be difficult to apply in modern work practice. If multiple work tasks exist, as in building construction, those tasks that are indoors or in the shade are best scheduled during midday hours wherever possible.

9.3 Personal Protective Measures for Outdoor Workers

9.3.1 *Clothing and hats*

Most summer clothing provides protection factors greater than 10. More than 85% of fabrics have protection factors of 20 or higher. Studies on the spectral transmission of textiles (Robson and Diffey 1990) show that many materials absorb more or less uniformly over the solar UVR spectrum. In other words, most clothing in common with other forms of shade such as trees, canopies and beach umbrellas provides principally a quantitative rather than qualitative (spectral) change in cutaneous UVR exposure. A number of factors affect the degree of protection including weave, color, weight, stretch and wetness (Gies et al 1994). Since the wearer cannot make a reliable assessment of the UVR protection of a fabric by visual inspection, standardized methods have been developed for specifying the “Ultraviolet Protection Factor (UPF)” [also known as the “Clothing Protection Factor (CPF)” in some countries] for a given fabric. This factor is defined as the ratio of the erythemally effective solar UVR exposure on exposed skin to that received through the fabric (AS/NZS 1996; BSI 1998). It is analogous to the Sun Protection Factor (SPF) quoted for sunscreens.

Hats can provide substantial shading of the head and neck from solar UVR. Those with wide brims provide the greatest protection for the skin of the face and neck. Legionnaire style hats, with a flap of fabric covering the neck, are particularly effective. The material from which the hat is constructed should have a high protection factor, although it is important to recognize that the actual protection level is less than the UPF, since the brim of a hat is not close to the skin. Most hats provide the best protection to the forehead. The relative amounts of protection over the whole of the head and neck are very dependent on the design of the hat, but offer very limited protection for the eyes. Like the shade structures discussed above, a hat provides greatest

protection where it shields the skin from most of the sky, in addition to the solar disc. Since the exact reduction in intensity provided by a hat depends on both the hat design and the prevailing solar elevation and cloud cover, sunscreens may also need to be applied to the face and neck to provide additional protection.

9.3.2 Sunscreens

Sunscreens are a secondary method of protection, and are advised only to be used to protect those parts of the body that cannot easily be protected by clothing. Unlike clothing, it is difficult to see which parts of the body have been missed when sunscreens are applied. Sunscreens can in some circumstances produce adverse skin reactions (e.g. photoallergy). Once applied, the level of protection diminishes with time in an unpredictable way, depending upon how it binds to the skin (substantivity), sweating, abrasion, or water immersion.

Topical sunscreens act by absorbing or scattering UVR. Sunscreens traditionally contained organic filters which absorb mainly UVB (e.g. octylmethoxycinnamate). However, in recent years, with growing concerns about the risks from exposure to UVA, the majority of suncare products now offer some protection from UVA, either by the addition of organic filters absorbing in this waveband (e.g., avobenzone) or mineral pigments (e.g. TiO_2 , ZnO).

A quantitative measure of the degree of protection afforded by a sunscreen is the SPF. It is popularly interpreted as how much longer skin covered with sunscreen takes to burn compared with unprotected skin (HEA 1996). A more appropriate definition of the SPF is that it is the ratio of the least amount of ultraviolet energy required to produce a minimal erythema on sunscreen (or clothing) protected skin to the amount of energy required to produce the same erythema on unprotected skin (FDA 1978). Ten years ago most commercially available sunscreen products had SPFs less than 10 but today there is a trend for much higher factors.

ICNIRP recommends that for adequate protection of sun-sensitive skin (see Section 3.2.2) an SPF of 30+ is appropriate for mid- and higher-latitudes and 45+ for the tropics and other extreme conditions. This may appear at first to be overly conservative. However, the following factors must be considered.

- *Application.* There is ample evidence that the numerical measure of protection indicated on the product pack is generally higher than achieved in practice. The protection factor is assessed in the laboratory for an application thickness of 2 mg/cm^2 (CIE, 1990); however, a number of studies have shown that consumers apply much less than this (Bech-Thomsen and Wulf 1993, Gottlieb et al 1997, Stenberg and Larkö 1985, Diffey and Grice 1997, Azurdia et al 1999) typically between 0.5 to 1.5 mg/cm^2 . This has a significant effect on protection with most users probably achieving a mean protection value of between 20-50% of that expected from the product label. Compounded with this is the likely variability of protection over the skin surface due to uneven application technique (Rhodes and Diffey 1996).

- *Durability.* Once a sunscreen has been applied to skin, its substantivity can become compromised due to factors such as immersion in water (Stokes and Diffey 1999), sweating and abrasion.
- *Protection Level.* For upright workers engaging in a variety of outdoor activity, the exposure relative to ambient on commonly exposed sites e.g. chest, shoulder, face, forearms (and lower legs if exposed), ranges from about 20% to 60% of available ambient (Diffey 1999). The maximum daily ambient ultraviolet levels under clear summer skies are about 70 SED in the tropics, 60 SED at mid-latitudes approximating those of southern Europe and the US, and 45 SED for UK and Scandinavian latitudes. Therefore, most outdoor workers even in the tropic, and certainly at mid-latitudes, would receive a daily exposure of no more than 40 SED over much of the body surface. Since an exposure of at least 2 SED is necessary for a minimal erythema in sensitive skin types, a photoprotective device, properly applied, would need only to possess a protection factor of 20 or more for tropical sun exposure. However, to account for inadequate application, a higher SPF is recommended. An SPF of at least 45 is advised in the tropics.
- To actually maintain exposures below the ICNIRP guidelines, current sunscreens would not be adequate. This would require the use of sunblock or appropriate clothing.

9.3.3 Eye Protection

Several forms of eyewear exist for protection of the eye. Sunglasses are frequently used to reduce the amount of solar radiation reaching the eye. The main casual use of sunglasses is usually to reduce glare by decreasing the luminance of visible radiation reaching the eye. Sunglasses also attenuate the UVR, but the degree of attenuation is not apparent by visual inspection of the lenses. Several countries have standards specifying the classification of sunglasses for the general use according to their UVR transmittance (AS/NZS 1996, ANSI 2001 1997). In Europe a standard exists for sunglare filters used in the workplace (CEN 1997). The design of sunglasses is important, with “wrap-around” glasses that fit close to the eyes providing better protection than more open designs. Photokeratitis and photoconjunctivitis are the main short-term effects of UVR irradiation of the eye. These conditions commonly occur when exposure takes place on a surface with a high UVR reflectance, such as snow or sand. The presence of the high reflectance ground surface significantly increases the solar irradiance reaching the eye. In addition, skiing often takes place at high altitudes where the solar UVB irradiance can be higher than that at sea level. UVR protective goggles are effective in reducing the ocular UVR exposure of the eyes from reflections from the snow.

For exposure to artificial sources in the outdoor work place, greater levels of protection may be needed in the form of enclosed goggles or faceshields, e.g., during electric arc welding in the field.

9.3.4 User acceptance of protective measures

UV protective measures must provide the proper level of protection (i.e. of UV absorption, area of coverage, et cetera) and also be accepted by the worker so that they are routinely used. A

protective measure (e.g. the application of a sunscreen, wearing a protective hat, garment or spectacle) that is not implemented provides no protection. A recent study (Weber et al 2007) identified preferences of a group of outdoor workers based upon issues such as fit, comfort and appearance rather than the actual physical protection afforded by the protective measure. These results are summarized in the following list.

- Synthetic micro fibre textiles (special UV protective clothing with a UPF of 50+) were usually preferred to cotton textiles since they allow the maintenance of an agreeable body climate even for hot air temperatures. However, cotton headwear was preferred over synthetic micro fibre headwear since the cotton absorbs perspiration and prevents ocular irritation by the sweat.
- Workers preferred grey or blue shirts over white shirts since white shirts were easily soiled causing an undesired appearance.
- Workers accepted neck protection except when the design was too extreme (Figure 9).



Figure 9. Neck protection with a rather extreme design (left) is often disliked while normal hat flaps were usually accepted (right) (adopted from Weber et al 2007).

- Ease of sunscreen application and the ability to apply sunscreens with dirty hands (e.g. with spray applicators) were preferred by workers surveyed.
- Sunscreens should not irritate the eyes, should not easily be rubbed off and should not clog skin pores. Smell of sunscreen can affect its acceptance (oily smell is not appreciated).
- Sturdy, scratch-resistant sunglasses with “wrap around” protection that minimize glare from light incident from the side were preferred and individual fit was considered very important (i.e. “one size fits all” is not easily achievable).

9.4 Health Surveillance

If occupational health programs for outdoor workers at risk from UVR exposure exist, they should address the adverse effects of solar UV exposure. Ideally, a physical examination should take place by the age of 20 to identify individuals having a high risk of skin cancer later in their life. Such an examination would include the following:

1. The medical history should document the number of severe sunburns, travels in sunny countries, practice of outdoor sports in open fields or water sports.
2. The examination should be focused on the detection of signs of skin sensitivity to UVR such as minor freckles on the face and/or shoulders, sun-induced, star-like, large freckles, and determine the number of nevi on arms, legs and trunk.
3. Identification of individuals at high risk should then include counseling on work assignments in UVR rich environments and adoption of strict photoprotective measures to minimize subsequent solar exposure.

If periodic medical surveillance is performed, examination of both the eye and skin is recommended. Skin examinations should include assessments of moles, keratoses and abnormal pigmentation. After age 20, periodic medical examinations may be advisable at a 5 year interval only if the individual is highly susceptible to UVR and working in a known high intensity solar environment. After detection of pre-malignant, solar keratoses Likewise ocular examination should include a complete evaluation of the anterior segment of the eye with emphasis on the observation of cataract, pterygium, droplet keratitis and pingueculum.

9.5 UV Risk Management for Outdoor Workers

Depending upon climate and governmental policies, the approach to risk management will differ. The role of competent authorities varies depending upon national legislation and regulations. However, there are several basic concepts that are normally addressed in any risk management program. For example:

- The recognition that solar UV radiation is an occupational hazard for all outdoor workers.
- Outdoor workers can receive many times the UV dose of indoor workers.
- The relevant national authority has to be convinced of the health risks of excessive levels of UV radiation in order to take action.
- Employers have to be convinced of their responsibility.
- There is a need to identify requirements for the program based upon a health risk assessment of the exposed worker population, using:
 - Solar ultraviolet radiation report: the UV Index
 - Evaluation of the seasonal environmental UVR effective exposure
 - Evaluation of the UVR effective exposure on unprotected skin and eyes (anatomical distribution)
 - Evaluation of UVR-skin spectral effectiveness
 - Customary outdoor clothing and special work clothing, etc.

Educating the worker is of paramount importance. Supervisors and safety personnel should communicate on the importance of prevention. Several points that have proven effective are:

- Appropriate shirts and caps with neck-flaps should be demonstrated and distributed.
- Loose-fitting, long-sleeve shirts are not necessarily “hot.”

Protecting Workers from Ultraviolet Radiation

- Encourage the use of sunscreens where appropriate. Sunscreen cream dispensers should be installed at the worksite to encourage use.
- Provision of information sheets (Appendix E), simple posters with cartoons, the use of slogans, and simple explanations of the Global Solar UV Index and the Shadow-Rule.

Program Assessment. In some past UV educational campaigns reviews have taken place after each summer by evaluation forms and periodic interviews. Evaluation of the quantity of sunscreens used, pictures taken during working hours and evaluation of workers wearing hats and appropriate clothes should be conducted. Interviews with randomly selected workers have focused on the link between precautions and their goal: “Good for the skin” or “Reduce skin cancer risk.”

In such a review, it has been found generally that the operation managers first have to be convinced of the need for the campaign. Younger workers are generally more compliant with the recommendations than older workers. Having reports in local newspapers, radio, or TV increases the awareness of the outdoor workers and the general population. The development of suitable summer clothing adapted to the workers has been recommended. Dispensers of non-greasy sunscreen creams have been distributed in numbers providing for easy access.

UVR exposure can be reduced by a number of appropriate measures and these all need to be evaluated for the particular type of work and locale. These include:

- Adjusting outdoor work hours.
- Shading structures for lunch and other breaks.
- Personal Protection by hat, by clothes by sunscreens and by protective sunglasses.

The campaign can be implemented by informing directors, operation managers, and supervisors by conferences and leaflets and by informing workers by leaflets and eye-catching posters, stickers, plasticized information cards, etc. Several precautionary tips should be stressed:

- Work in the shade whenever possible, especially between 11:00 and 15:00 (assuming local solar noon at ~ 13:00).
- Wear long trousers and long-sleeved shirts (or at least T-shirts).
- Wear a broad-brimmed hat, a peaked cap (or a hard hat).
- Apply sunscreen with a protection factor of SPF 15-30 every 2 hours.

The Shadow Rule and the UVI

The Shadow Rule simply advises a person that if his or her shadow is not longer than their height, then UV protective precautions are important. It recognizes the importance of atmospheric slant path for the sun’s UV rays. The Global Solar UV Index (UVI) formulated by the WHO, WMO, UNEP and ICNIRP to communicate a uniform message regarding the day’s UV exposure conditions indicates the general level of risk, whereas the shadow rule provides a simplified method to determine when the UVI exceeds 4, provided that shadows exist. Simple concepts that everyone can understand such as the “Slip, Slap, Slop and Seek Shade” slogans are important. This slogan translates to “Slip on a shirt, slap on a hat, slop on a sunscreen and seek shade” (Cancer Council Victorias SunSmart Program, <http://www.sunsmart.com.au>).

Another protection policy issue relates to the use of sunglasses and the ocular susceptibilities. All workers of various skin types are more-or-less equal in susceptibility to cataract, pterygium and other ocular diseases associated with UV radiation. However, the role of ambient temperature with UV is not yet clearly understood, and the latitudinal change in nuclear cataract incidence suggests that ambient temperature may also play a role. If sunglasses are worn, the wrap-around designs are needed to avoid limbal focusing (Coroneo Effect).

10. Protective Measures for Artificial Sources of UVR

10.1 Introduction

Protection against UVR emitted from artificial sources is generally straightforward where sources are used in a controlled work environment. The basic principles of control by engineering measures, administration, and the provision of protective clothing, can be applied. A notable exception is arc welding, where the process may be carried out in a place, to which others not directly involved in the welding process, may have access.

Ideally, engineering controls should ensure that UVR radiation at levels hazardous to health is contained within the source or its immediate enclosure. Where the application of such engineering controls is not practical, administrative controls should be applied aimed at ensuring that workers are made aware of the presence of potentially harmful UVR and providing information to avoid such harmful exposure. When the nature of the work requires accomplishment of a task close to a source where neither engineering controls nor administrative controls are practical, personal protective clothing should be provided and worn.

10.2 Engineering Controls

10.2.1 Use of enclosures and screens

The use of 'light-tight' cabinets and enclosures, UVR-absorbing glass and plastic shielding and baffles is a key engineering control. Shields, curtains and baffles and suitable separation distance can be used to protect workers from UVR emitted by open arc processes such as arc welding, arc cutting and plasma spraying. However, in such processes administrative controls and particularly personal protective clothing are also important.

Indiscriminate emissions of UVR should be avoided in the workplace. This can be prevented by carrying out the process within a sealed housing or by providing a screened area. Sealed housings may have observation ports, made of suitably tested UVR-absorbent material such as certain grades of acrylic, PVC and window glass. Screened areas are necessary where the exposure process takes place external to the source housing. Such an area should be subject to administrative controls (see section 10.3) and people should not normally have access to this area. In situations where people may enter the area, they should be adequately protected from UVR. Containment is an important protective measure where public access is likely.

10.2.2 Use of interlocks

Where direct access to the source is required, for example for maintenance, fail-safe interlocks manufactured, installed, tested and used to agreed relevant technical standards, should be used (Figure 8).

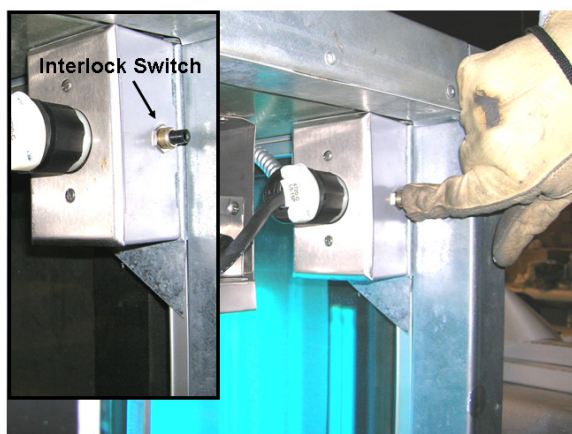


Figure 8. Example of an interlock switch on the door of a Lumalier™ ultraviolet germicidal irradiation system. When the door to the system is open (upper left insert), the power to the UV lamps is off prohibiting exposure to UVR. When the door is closed (as simulated on the right), the UV lamps are on.

10.2.3 Elimination of reflected UVR

Many surfaces, especially those that are visibly shiny, are often good reflectors of UVR. To reduce the intensity of reflected radiation, surfaces can be coated or painted with appropriate non-UVR reflective material.

10.2.4 Ventilation and mechanical hazards

Ventilation may be needed to safely exhaust ozone produced by UVC. Threshold limit values (TLVs) for controlling occupational exposure to ozone expressed in terms of time-weighted-average concentrations for an 8 hour working day are published by the American Conference of Governmental Industrial Hygienists (ACGIH 2004).

If the pressure within a source is significantly different from atmospheric pressure, consideration should also be given to the risk of explosion/implosion.

10.3 Administrative Control Measures

10.3.1 Training

People working with a UVR source or maintaining such a source should be provided with adequate training to understand the need for control of the hazards involved and to carry out their work safely.

10.3.2 Limitation of access

Access to an indoor work area where hazardous levels of UVR exist should be restricted to those informed of the potential hazards and trained in appropriate protective measures. Reducing the time of exposure and increasing the distance of a worker from the source can be used as effective control measures. The exposure duration should be kept to a minimum, and if a source is not enclosed, the user should keep as far away from the source as is practicable.

10.3.3 Hazard warnings and signs

Hazard warning signs should be used to indicate the presence of a potential UVR hazard when exposures are likely to exceed recommended exposure limits and indicate restriction of access, as illustrated in Figure 9, and if appropriate the need for personal protection. Warning lights may also be used to show when the equipment is energized.

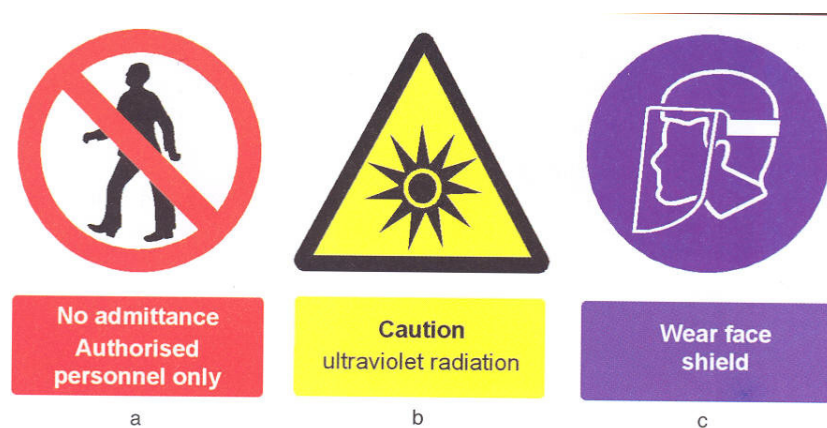


Figure 9. Typical signs used in the work environment to advise of hazards and recommend the use of personal protective equipment

10.4 Personal protection

Where, because of the nature of the work, for example the need to carry out a task close to a source, and neither engineering nor administrative controls are practical, personal protection is required.

10.4.1 Protection of the skin

For occupational exposure to artificial sources, the areas of the skin most usually at risk are the backs of the hands, the face, the head and the neck, as other areas are generally covered by working clothes. The hands can be protected by wearing gloves with low UVR transmission. The face can be protected by a UVR-absorbing face shield or visor, which may also offer eye protection. Suitable headwear will protect the head and neck.

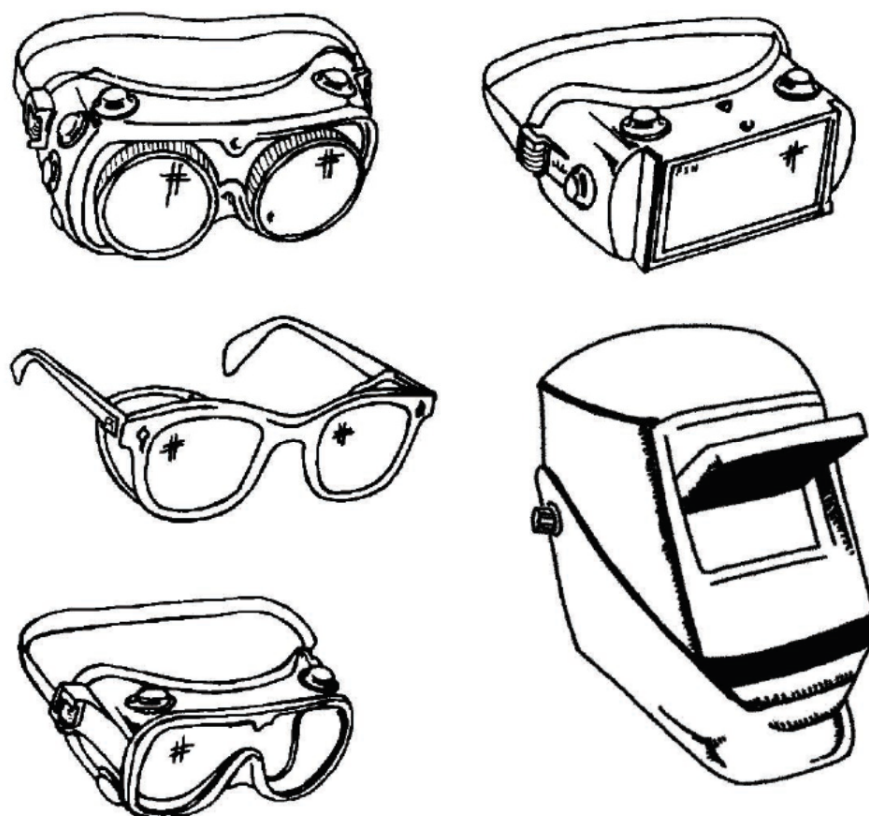


Figure 10. Various degrees of UVR protection to the eyes, head and neck provided by protective eyewear and clothing (adapted from Sliney 2005)

10.4.2 Protection of the eyes

Goggles, spectacles, visors or face shields, which absorb UVR, should be worn where there is a potential eye hazard (Figure 10). The highest levels of UVR commonly encountered are during electric arc welding, which produces high levels of all wavelengths of UVR, including substantial irradiance in the UVC region. There is also the possibility of retinal damage from the intense visible radiation emitted. Welders should be protected by a welding helmet or mask fitted with absorption filters meeting appropriate standards, as illustrated in Figure 11. Eyewear for outdoor occupational use should provide protection to both direct and peripheral exposure of the

eyes. Close fitting face masks with low transmittance to UVR, visible and infrared radiation are used for protection.



Figure 11. Welder with appropriate personal protective equipment for the eye and skin (Photograph courtesy of Finnish Institute of Occupational Health)

11. Conclusion and Remaining Medical Questions

The boundaries between the risks and the benefits of UVR radiation are not clearly defined. Although the UVR health risks associated with excessive exposure to the eye and skin are known, it is not clear whether there are benefits from UVR exposure at levels above the ICNIRP Guideline. It is recognized that the risks of UVR exposure differ greatly depending on skin phototypes. For dark skin population, the position and quality of melanin in the stratum corneum provide a very important shield against UVB; however, this absorption minimizes the production of Vitamin D in this population. Therefore, it is important that UVR exposure of dark skin phototypes not be limited but skin protection must be emphasized for skin phototypes I – IV. However, eye protection against UVR should be emphasized for all skin phototypes particularly with conditions of high ground reflectance. The geometry of UVR exposure plays a major role in determining exposure dose (Slaney 1995).

Additional medical research is required to determine the UVR exposure conditions that result in better defined beneficial/detrimental effects.

- For individuals who are able to tan or are naturally melano-protective, repeated low-level exposure (as naturally occurs during early spring) is beneficial for the outdoor worker by providing a significant acquired photoprotection against further exposure and long term detrimental consequences.
- UVB exposures provide essential vitamin D production in human skin and for the darkest skin individuals (phototype 6) the presence of high concentrations of melanin in the stratum corneum inhibits severely vitamin D production particularly in northern countries. There are still uncertainties in the amount and area of skin exposed required to provide adequate vitamin D production.
- Severe sunburns and cumulative UVR exposures are the two factors which have been recognized as responsible for skin cancers. Currently the contribution of UVA is considered as dangerous as the contribution of UVB for inducing all forms of skin cancers considering the far greater amount of UVA compared to the UVB in the normal solar exposure. Current evidence suggest that for melanoma and basal cell carcinoma, UVR exposure early in life (before working age) seems to be the major causative factor; however cumulative exposures are without doubt responsible for some forms of melanoma. Further research is needed in this area.
- Recent mouse model mimicking the most frequent human melanoma demonstrated the critical role of UVB delivered shortly after birth and apparent absence of efficacy of UVA delivered later in life. Further studies in this attractive experimental model are warranted (De Fabo et al 2004).
- Since the UVR health risk is strongly dependant on skin phototypes, more work is needed to improve effective risk communications that is applicable to all and particularly to the melano-compromised workers.
- Since the protective efficacy of sunscreen products depends on many technical factors, more work is needed to adequately characterize their protection and communicate proper use. In parallel, improvement of sun protective fabrics that can be employed in loose-fitting work clothes designs is needed particularly where protection against heat stress is required.
- Further studies of UVR protective eyewear are required to protect the eye against radiation incident from the side (ground protection et cetera) and also balance the luminous transmittance with work task requirements.

APPENDIX A

RADIOMETRIC TERMS AND UNITS

Prior to any meaningful determination of the optical radiation exposure of biological tissues, it is necessary to define the relevant quantities and units. For all photobiological effects, it is necessary to measure the appropriate radiometric quantity. The surface exposure dose rate is termed the *irradiance*, with units of watts-per-square-centimeter (W/cm^2), and the surface exposure dose is termed the *radiant exposure*, with units of joules-per-square-centimeter (J/cm^2). There are also parallel dose rate and dose concepts within scattering tissue, and these quantities are termed *fluence rate*, also with units of watts-per-square-centimeter (W/cm^2), and dose within tissue that is termed the *fluence*, also with units of joules-per-square-centimeter (J/cm^2). The existence of two terms for the same radiometric unit seems curious, and this has confused many scientists, with the result that the terms are frequently misused for the other. But the concepts are different and the distinctions are important. The quantities irradiance and radiant exposure are what instruments measure at the exposed surface (and follow Lambert's Cosine Law), but fluence rate and fluence include backscattered light and are useful for photochemical calculations within tissue (as in photodynamic therapy).

Table A-1. Useful Radiometric Units ^{1,2}

Term	Symbol	Definition	Unit and abbreviation
Radiant Energy	Q	Energy emitted, transferred, or received in the form of radiation	joule (J)
Radiant Power	P	Radiant energy per unit time	watt (W) defined as J/s
Radiant Exposure (Dose in Photobiology)	H	Energy per unit area incident upon a given surface	joules per square centimeter (J cm^{-2})
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E	Power per unit area incident upon a given surface	watts per square centimeter (W cm^{-2})
Integrated Radiant Intensity	Ip	Radiant energy emitted by a source per unit solid angle	joules per steradian (J sr^{-1})
Radiant Intensity	I	Radiant power emitted by a source per unit solid angle	watts per steradian (W sr^{-1})
Integrated Radiance	Lp	Radiant energy emitted by a source per unit solid angle per source area	joules per steradian per square centimeter ($\text{J sr}^{-1} \text{ cm}^{-2}$)
Radiance ³	L	Radiant power emitted by a source per unit solid angle per source area	watts per steradian per square centimeter ($\text{W sr}^{-1} \text{ cm}^{-2}$)
Optical Density	OD	A logarithmic expression for the attenuation produced by a medium $OD = -\log_{10} \left(\frac{\Phi_L}{\Phi_O} \right)$	unitless Φ_O is the incident power Φ_L is the transmitted power

Notes: 1. The units may be altered to refer to narrow spectral bands in which the term is preceded by the word *spectral* and the unit is then per wavelength interval and the symbol has a

subscript λ . For example, spectral irradiance E_λ has units of $\text{W m}^{-2} \text{m}^{-1}$ or more often, $\text{W cm}^{-2} \text{nm}^{-1}$.

2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the terms below and the nm or μm are most commonly used to express wavelength.

3. At the source $L = \frac{dI}{dA \cos \theta}$ and at the receptor $L = \frac{dE}{d\Omega \cos \theta}$

Photobiological Quantities

In photobiology, the concept of a biologically effective dose is of critical importance. Since not all wavelengths of UVR are equally effective in producing a biological effect, an action spectrum $A(\lambda)$, which defines the relative effectiveness of different wavelengths, is determined. This relative response curve is generally normalized to provide a maximal value of 1.0 at the wavelength of maximal tissue sensitivity. When considering health effects of UVR, an effective exposure rate (i.e., irradiance) E_{eff} (or the exposure summed over time, i.e., the effective radiant exposure H_{eff}) is calculated by spectral weighting as follows: the spectral irradiance E_λ at the surface of the exposed biological tissue is mathematically weighted against the action spectrum of the biological response $A(\lambda)$ across the relevant spectrum (e.g., from 200 nm to 400 nm) and is shown as follows:

$$E_{\text{eff}} = \sum E_\lambda A(\lambda) \Delta\lambda \quad [1]$$

The effective exposure dose (or effective radiant exposure) H_{eff} is the product of the exposure duration t , in seconds, and the effective irradiance E_{eff} (spectrally weighted UVR):

$$E_{\text{eff}} (\text{in } \text{W cm}^{-2}) t = H_{\text{eff}} (\text{in } \text{J cm}^{-2}) \quad [2]$$

Equation [2] can also be rearranged to calculate the exposure time t necessary to reach a reference exposure dose for the given response.

$$t = H_{\text{eff}} (\text{in } \text{J cm}^{-2}) / E_{\text{eff}} (\text{in } \text{W cm}^{-2}) \quad [3]$$

For example, the exposure duration t_{erythema} necessary to achieve a minimum erythematous dose (MED) in an individual would be the MED for that individual, e.g., 220 J m^{-2} divided by the erythemally weighted irradiance E_{erythema} [weighted against the appropriate erythematous action spectrum $E(\lambda)$].

$$t_{\text{erythema}} = (220 \text{ J m}^{-2}) / E_{\text{erythema}} (\text{W m}^{-2}) \text{ seconds} \quad [4]$$

As another example, the exposure guidelines that are referred to in Appendix F apply an analogous formula using a different spectral weighting, a hazard action spectrum, $S(\lambda)$.

Note that the relationship between an exposure and the biological response may not be simple. There may be grades of reaction above a just-detectable threshold, and the action spectrum may differ for different grades of reaction. The photobiological response is usually not immediate, and it may only occur with exposure above a certain threshold (e.g. sunburn). Thus, whenever an action spectrum is specified, it is important to describe the end-point upon which it is based. The normal responses of eyes and skin to UVR can be classed under two headings: acute effects and chronic effects. An acute effect is one of rapid onset and generally of short duration, as opposed to a chronic effect, that is often of gradual onset and long duration.

The Global Solar UV Index

A specialized, but widely used, measure of UV exposure rate is the Global Solar UV Index. The Global Solar UVI is formulated using the CIE reference action spectrum for UV-induced erythema in the human skin (McKinlay and Diffey 1987, Joint ISO 17166:1999/CIE S007/E-1998). It is a measure of the UV radiation that is relevant to and defined for a horizontal surface irradiated by sunlight. The UVI (I_{UV}) is a unitless quantity defined by the following formula:

$$I_{UV} = k_{er} \int_{250nm}^{400nm} E_{\lambda} S(\lambda) d\lambda \quad [5]$$

where E_{λ} is the solar spectral irradiance expressed in $W m^{-2} sr^{-1} nm^{-1}$ at wavelength λ , $S(\lambda)$ is the erythema reference action spectrum and k_{er} is a constant equal to $40 m^2 W^{-1}$.

APPENDIX B

EXPOSURE FACTORS

Table B-1. Sunlight exposure (relative to 100% on vertex) for rotating mannequins and living subjects engaged in tennis, golf, gardening or walking

Site	Mannequin	Living subjects		
	Diffey et al 1977	Gies et al 1992	Holman et al 1983	Herlihy et al 1994
Cheek	31	24	15	13
Hand	50	-	24	29
Shoulder	75	94	66	43
Back	43	36	58	40
Chest	68	50	44	23
Thigh	33	-	16	25
Calf	-	-	-	27

Table B-2. Solar ultraviolet exposure on the head taken from a number of studies on living subjects and mannequins

Site	Relative exposure
Vertex	100
Forehead	20-65
Nose	20-65
Cheek	15-40
Chin	20-35
Back of neck	20-35

Table B-3. Exposure ratio for rotating headform models as a function of tilt angle (Airey et al 1995)

Site	0° (mean)	10°	20°	30°	40°	60°
Vertex	1.00	0.95	0.98	0.87	0.71	0.43
Forehead	0.39	0.31	0.24	0.16	0.10	0.06
Nose	0.59	0.52	0.41	0.27	0.15	0.11
Cheek	0.29	0.16	0.20	0.10	0.08	0.07
Neck	0.21	0.27	0.45	0.56	0.63	0.65

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Table B-4. Exposure ratio for human subjects performing various activities (Airey et al 1995)

Site	Standing	Sitting	Bending	Kneeling
Vertex	1.00	1.00	1.00	1.00
Forehead	0.27	0.18	0.06	0.06
Nose	0.41	0.29	0.18	0.13
Cheek	0.27	0.25	0.12	0.15
Neck	0.50	0.57	0.52	0.69

Table B-5. Relative fraction UVR exposures of shoulders and chest among physical education teachers (PE), school grounds staff and lifeguards, Sunshine Coast, Queensland, using polysulphone badges and actinic UVR detector, according to the number of SED (100 J.m⁻²). Mean of 5 days and typical conditions for clear sky or cloudy sky (adapted from Gies et al 1995).

	Ambient UVR (in SED)		PE Teachers		School Staff		Lifeguards	
	UV Detector	PolyS	shoulder	chest	shoulder	chest	shoulder	chest
clear sky	48	51	0.23	0.11	0.20	0.08	0.13	0.08
cloudy	15	11	0.15	0.10	0.23	0.13	0.13	0.11
Weekly average			0.19	0.085	0.18	0.08	0.12	0.10

Note: Values are expressed as a fraction of the total daily ambient UVR.

Table B-6. Comparison of data from several authors: measurements of UVR exposures of outdoor workers and during different outdoor recreational activities.

References	Chest badges	Shoulder badges
Larkö and Diffey (1983)	0.1 - 0.7 of ambient UVR	
Holman et al (1983)	0.46	0.70
Herlihy et al (1994)	0.14	0.30
Gies et al (1995)	0.10	0.20

Note: Values are expressed as a fraction of the total daily ambient UVR.

Table B-7. Reflectance of ICNIRP-effective solar UVB from terrain surfaces

Terrain surfaces	Diffuse reflectance ICNIRP effective solar UVB
Green mountain grassland	0.8 - 1.6 %
Dry grassland	2.0 - 3.7 %
Wooden boat deck	5 - 7 %
Black asphalt	5 - 9 %
Concrete pavement	8 - 12 %
Atlantic beach sand (dry)	15 - 18 %
Atlantic beach sand (wet)	7%
Sea foam (surf)	25 - 30 %
Dirty snow	59%
Fresh snow	88%

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Table B-8. Measured ICNIRP effective UVB from the sky with a 40° cone field of view

Sky conditions location, elevation	Zenith reading ($\mu\text{W cm}^{-2} \text{sr}^{-1}$)	Directly at sun ($\mu\text{W cm}^{-2} \text{sr}^{-1}$)	Opposite sun ($\mu\text{W cm}^{-2} \text{sr}^{-1}$)	Horizon sky ($\mu\text{W cm}^{-2} \text{sr}^{-1}$)
Clear sky, dry, sea level	0.1	1.4 Z=70°	0.22	0.27
Clear sky, humid, sea level	0.27	4.1 Z=50°	0.27	0.24
Ground fog, sea level	0.04	0.19 Z=75°	0.04	0.03
Hazy humid, sea level	0.014	1.4 Z=70°	0.22	0.54
Cloudy bright, 700 m	0.54	0.44 Z=45°	0.27	0.05
Hazy beach	0.54	0.60 Z=75°	0.54	0.60
Hazy beach	0.38	3.5 Z=40°	0.54	0.44
Clear mtn top 2750 m	0.54	1.6 Z=25°	0.82	0.08

APPENDIX C

ADDITIONAL INFORMATION ON THE BIOLOGICAL EFFECTS OF ULTRAVIOLET RADIATION

EFFECTS OF SOLAR UV RADIATION ON THE SKIN

The normal responses of skin to UV radiation can be classed under two headings: acute effects and chronic effects. An acute effect is one of rapid onset and generally of short duration, as opposed to a chronic effect, that is often of gradual onset and long duration.

Sunburn

Sunburn, or erythema, is an acute injury following excessive exposure to solar UV radiation, and is most pronounced for lightly pigmented skin types. The redness of the skin which results is due to an increased blood content of the skin by dilatation of the superficial blood vessels in the dermis, mainly the subpapillary venules. Half an hour of midday summer sunshine in northern Europe on the unacclimatized skin of very lightly pigmented Caucasian subjects is normally sufficient to result in a subsequent mild reddening of the skin. Following this degree of exposure erythema may not appear for about 4 hours, although measurements using an instrument more sensitive than the eye at detecting erythema showed that vasodilatation begins to occur much sooner (Gezondheidsraad 1986). The erythema reaches a maximum at about 8-12 hours after exposure and fades after a few days. Exposing the skin for increasing periods to strong summer sunshine progressively shortens the time before the appearance of erythema, lengthens its persistence, and increases its intensity. High doses may result in edema, pain, blistering, and, after a few days, peeling.

Action Spectrum for Ultraviolet Erythema

The ability of UVR to produce erythema in human skin is highly dependent upon the radiation wavelength, and is expressed by the erythema action spectrum. Erythema action spectra have been the subject of experimental and theoretical interest for over 70 years. The International Commission on Illumination (CIE) reference action spectrum $E(\lambda)$ as shown in Figure C1, is routinely used to convert absolute UV exposure levels into erythemally effective irradiance (McKinlay and Diffey 1987, CIE 1998).

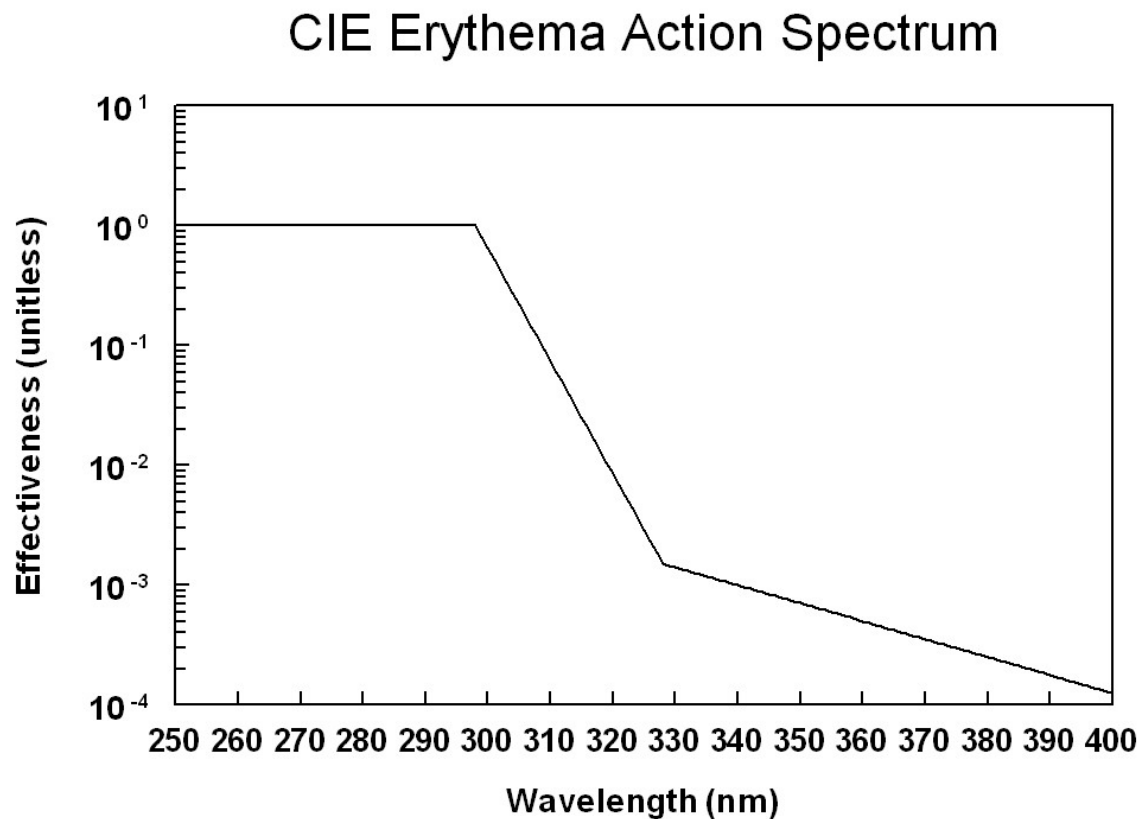


Figure C1. CIE erythema action spectrum (McKinlay and Diffey 1987, CIE 1998)

Factors Influencing the Development of Sunburn

Skin color is an important factor in determining the ease with which the skin will sunburn. Whereas fair-skinned people require only about 15-30 minutes of midday summer sunshine to induce an erythematous reaction, people with moderately pigmented skin may require 1-2 hours exposure and those with darkly pigmented skin will not normally sunburn. Other phenotype characteristics that may influence the susceptibility to sunburn are hair color, eye color and freckles. Based on a personal history of response to 45-60 minutes of exposure to midday summer sun in early June, individuals can be grouped into one of six sun-reactive skin types (Fitzpatrick 1975, Fitzpatrick et al 1983). These skin types fall into three more significant groups: melano-compromised, melano-competent, and melano-protected (Césarini 1995).

There are anatomical differences in erythematous sensitivity. The face, neck and trunk are two to four times more sensitive than the limbs (Olson 1966). These anatomical differences are compounded by the variations in solar exposure on different parts of the body. Vertical surfaces of an upright person receive about one third of the ambient UV radiation, whereas horizontal surfaces, such as the epaulette region of the shoulder, receive up to 75%. There is no difference in sunburn susceptibility between sexes. Although erythematous sensitivity may change with age

[young children and elderly people are said to be more sensitive (Hawk 1982)], quantitative studies of erythral sensitivity in subjects of these age groups have not confirmed this (Cox et al 1992).

Skin Thickening

Thickening (epidermal hyperplasia) of the epidermis is a significant component of a mild sunburn reaction. A single moderate exposure to UVB can result in up to a three-fold thickening of the stratum corneum within one to three weeks, and multiple exposures every one to two days for up to seven weeks will thicken the stratum corneum by about three to five-fold (Miescher 1930). Skin thickness returns to normal about one to two months after ceasing radiation.

Thickening of the skin, especially of the stratum corneum, after sun exposure can lead to a significant increase in protection against UVR by a factor of five or even higher. In Caucasians skin thickening is probably more important than tanning in providing endogenous photoprotection, although in darkly pigmented races it is likely that skin pigmentation is the most important means of protection against solar UVR.

Tanning

The delayed pigmentation of the skin known as tanning, or melanin pigmentation, once considered undesirable, became socially desirable in many cultures during the last century. Melanin pigmentation of skin is of two types:

- (i) constitutive - the color of the skin seen in different races and determined by genetic factors only
- (ii) facultative - the reversible increase in tanning in response to solar UV radiation (and other external stimuli)

Immediate Pigment Darkening (IPD)

This is a transient darkening of exposed skin that can be induced by UVA and visible radiation (Rosen et al 1990). In general, the greater the constitutive tan, the greater is the ability to exhibit IPD. Immediate tanning can become evident within 5-10 minutes of exposure to summer sun and normally fades within 1-2 hours. Melanin photochemistry is considered to be the predominant mechanism of IPD (Beitner 1985, Honigsmann et al 1986).

Delayed Tanning

The more familiar delayed tanning becomes noticeable within a day or two after sun exposure, gradually increasing for several days and persisting for a week or longer. The tanning process increases the number of melanin granules throughout the epidermis. Although a tanned skin does confer a degree of photoprotection, such protection seems to be no more than a factor of two to three being achieved in the absence of skin thickening (Kaidbey 1978). Melanin is not an effective sunscreen for Caucasian skin and it has been suggested (Morison 1985) that, contrary to popular belief, melanin is not an evolutionary adaptation to protect humans from the damaging effects of sunlight.

Action Spectrum for Tanning

The doses of UVR at different wavelengths necessary to induce delayed tanning were determined by Parrish et al (1982) for subjects with sun reactive skin types I and II (poor

tanners) and by Gange et al 1986 for subjects who tan well (skin types III and IV). The action spectra obtained corresponded broadly with the erythema action spectrum. The threshold doses at all wavelengths for erythema and pigmentation were similar for poor tanners, whereas in those subjects who are genetically capable of tanning easily the melanogenic doses in the UVA region were approximately one quarter of the doses required to produce a minimal erythema. Melanogenesis can be stimulated in individuals who tan well with suberythema doses of solar UVR (Pathak and Fanselow 1983).

Production of Vitamin D₃

The best-established beneficial effect of solar UVR on the skin is the synthesis of vitamin D₃ acquired well before there is a danger of erythema. Solar radiation in the UVB waveband photochemically converts 7-dehydrocholesterol in the epidermis to previtamin D₃, which is converted to vitamin D₃. Sunlight further regulates and limits the production of vitamin D₃ in the skin to preclude a toxic level. Due to the photoinstability of previtamin D₃, short but repeated exposures to sunlight are more beneficial than rare but extended exposures.

Several factors influence the capacity of the skin to synthesize vitamin D₃. The main determinant is the potentially available UVB which depends on latitude and at a given latitude on season and time of the day (Slaney 2006). There are areas in the world where there is insufficient ambient UVB for several months of the year (Webb 2005). Furthermore, increased melanin pigmentation in the skin can limit the production of vitamin D₃ (Clemens et al. 1982), as can increasing age (MacLaughlin and Holick 1985). Other important factors are personal characteristics with respect to clothing and the use of sunscreens, and behavior (outdoor activities, etc.). Recent studies revealed a surprisingly high rate of vitamin D₃ deficiency in several populations. It is well established that a lack of adequate vitamin D₃ is responsible for bone and muscle disorders, but there is also some evidence of an increased risk of autoimmune diseases as well as limited evidence for a possible association with colon and some other cancers. Despite these facts, there was a general consensus among UV and Vitamin D₃ experts, that the most practical and effective solution to correct vitamin D deficiency appears to be through the use of supplements and food fortification rather than extending sun exposure or using sunbeds (reviewed in ICNIRP 2006).

Photoaging

The clinical signs of a photo-aged skin are dryness, deep wrinkles, accentuated skin furrows, sagging, loss of elasticity, mottled pigmentation and telangiectasia (Leyden 1990). These characteristics reflect profound structural changes in the dermis (Kligman 1986). It has been speculated (Leyden 1990) that perhaps as much as 80% of solar UV induced photo-aging occurs within the first 20 years of life with the exception of those whose occupation or life style results in extensive exposure as adults.

Action Spectrum for Photoaging

The relative importance of different wavelengths in aging human skin cannot be readily determined because of the long latent period and slow evolution of photoaging. Instead, extrapolation from experiments using hairless mice (Bissett 1989, Kligman 1991) or the miniature pig (Fourtainier 1989) is relied upon. Since approximately one third of UVA radiation and less than 10% of UVB radiation incident on white skin penetrates to the dermis (Bruls et al 1984), it is not surprising that results from animal studies (Bissett 1989) have shown that chronic UVB and UVA irradiation in hairless mouse skin both result in histological, physical and visible

changes characteristic of photoaging. The UVB radiation was only 20-50 times more efficient than UVA; this is in marked contrast to sunburn, suntan and non-melanoma skin cancer where UVB is about 1000 times more effective than UVA (vide infra).

It should be remembered that solar radiation includes not only UVR but also visible and infrared radiation. Visible light is thought to be unimportant in photoaging (Kligman 1986) but studies have confirmed that infrared radiation can certainly damage the dermal matrix (Kligman 1984).

Skin Cancer

The three common forms of skin cancer, listed in order of severity are: basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and malignant melanoma (MM). Around 90% of skin cancer cases are of the non-melanoma variety (BCC and SCC) with BCCs being approximately four times as common as SCCs. Exposure to UVR is considered to be a major etiological factor for all three forms of cancer (IARC 1992). For basal cell carcinoma and malignant melanoma, neither the wavelengths involved nor the exposure pattern that results in risk have been established with certainty; whereas for squamous cell carcinoma, both UVB and UVA are implicated and the major risk factors seem to be cumulative lifetime exposure to UV radiation and a poor tanning response.

Squamous Cell Cancer

The evidence that exposure to sunlight is the predominant cause of squamous cell cancer in man is very convincing. These cancers occur almost exclusively on sun-exposed skin such as the face, neck and arms, and the incidence is clearly correlated with geographical latitude, being higher in the more sunny areas of the world (Kricger 1994). Recent epidemiological studies suggest that sun exposure in the 10 years prior to diagnosis may be important in accounting for individual risk of SCC (Gallagher et al 1995).

Basal Cell Cancer

The relationship between basal cell carcinoma and sunlight is less compelling, but the evidence is sufficiently strong to consider it also to be a consequence of exposure to sunlight. Whilst SCC is strongly related to cumulative lifetime exposure to sunlight, this relationship is not so convincing for BCC (Gallagher et al 1995, Kricger 1995), and it may be that sun exposure in childhood and adolescence may be critical periods for establishing adult risk for BCC (Gallagher et al 1995).

Action Spectrum for Non-Melanoma Skin Cancer

Clearly an action spectrum for skin cancer can only be obtained from animal experiments. The most extensive investigations to date are those from groups at Utrecht and Philadelphia. These workers exposed a total of about 1100 white hairless mice to 14 different broad-band ultraviolet sources and by a mathematical optimization process derived an action spectrum referred to as the Skin Cancer Utrecht-Philadelphia (SCUP) action spectrum (de Gruijl et al 1994). The SCUP action spectrum is that for skin tumor induction in hairless mice, a species which has a thinner epidermis than humans. By taking into account differences in the optics of human epidermis and hairless albino mouse epidermis, the experimentally-determined action spectrum for tumor induction in mouse skin can be modified to arrive at a postulated action spectrum for human skin cancer (de Gruijl et al 1994). The resulting action spectrum resembles the action spectrum for erythema (Figure C1).

Malignant Melanoma

During the past 40 years or so there has been an increase in the incidence of malignant melanoma in white populations in several countries. There exists an inverse relationship between latitude and melanoma incidence and this has been taken as evidence for a possible role of sunlight as a cause of malignant melanoma. However, this pattern is not always consistent. In Europe, for example, the incidence and the mortality rates in Scandinavia are considerably higher than those in Mediterranean countries. This inconsistency may reflect ethnic differences in constitutional factors and customs. Also, the unexpectedly low incidence in outdoor workers, the sex and age distribution, and the anatomical distribution have pointed to a more complex association (Armstrong 1994).

There is now growing evidence that intermittent sun exposure - mainly from recreational activities - rather than cumulative or chronic exposure associated with occupation is associated with increased risk of developing malignant melanoma. Several studies have established a history of sunburn as an important risk factor for melanoma development, although in these studies a potential for recall bias exists. Migration studies have led to the suggestion that sun exposure in childhood is a particularly critical period in terms of melanoma risk.

Action Spectrum for Melanoma

The only data that exist on an action spectrum for melanoma induction are those obtained from irradiating hybrids of a small tropical fish with different wavelengths of UVR (Setlow et al 1993). The action spectrum obtained in this study showed that all wavelengths of UV radiation may be important in melanoma, unlike non-melanoma skin cancer in which the causative wavelengths are largely within the UVB spectrum.

Eye Damage

The prevalence of the blinding disease of cataract world-wide exceeds 50 million. The prevention and slowing of the progress of lenticular opacities is an important objective in public health (WHO, 1994). Animal experiments have clearly shown that UVR produce cataract and refined epidemiological data show an increase risk of cortical cataract with UVB exposure (Taylor et al 1988, WHO, 1994). Experts disagree on the degree of importance played by UVR in cataractogenesis, and this controversy is fueled by poor ocular dosimetry.

Ocular exposure is far more affected by the geometry of exposure than is skin exposure.

Although the cornea is more sensitive to UVR injury than the skin, injuries are not often experienced because of shading by the upper lid and behavioral avoidance of direct sunlight exposure of the eye. Thus snow-blindness (photokeratitis) is rarely experienced compared to sunburn of the skin unless the ground is highly reflective (e.g., as with snow). Individuals do not look directly overhead when the sun is very hazardous to view, whereas most people may stare at the sun when it is comfortable to observe near the horizon. Fortunately, at sunset, the filtering of UVR and blue light by the atmosphere allows a direct view at the sun. When the solar elevation angle exceeds 10 degrees above the horizon, strong squinting is observed which effectively shields cornea and retina from direct exposure (Slaney 1994). These factors reduce the exposure of the cornea to a maximum 5% of that falling on the exposed top of the head. However, if the ground reflectance exceeds 15%, photokeratitis may be produced following 1-2 hours of midday

exposure. Otherwise, the photokeratitis threshold would be achieved in less than 15 minutes for midday summer sun.

When wearing sunglasses, the pupil and lids open proportionally to the darkness of the sunglasses. Coroneo et al (Coroneo et al 1991, Coroneo et al 1993) have shown that very oblique temporal rays can be refracted into the critical nasal equatorial region of the lens and this could explain the increased incidence of opacification originating in the nasal sector of the lens in cortical cataract. The protective value of upper and lower lids, when they close down during squinting, determines the ocular UVR exposure dose in different environments. Brimmed hat or other headwear, associated or not with dark sunglasses, will modify greatly the UVR exposure dose.

Exposure to sunlight, particularly the UVB component, is believed to be associated with a variety of eye disorders, including damage to the cornea, lens and retina (Young 1994). Cataracts are the most frequent effect, while photokeratitis (snowblindness), droplet keratopathies and pterygium (a fleshy growth on the conjunctiva) also result from UVB exposures. Cataracts are a major cause of blindness in both developed and developing countries. However, the relative the importance of different wavelengths in cataractogenesis, as well as dose relationships, are still debated. Animal studies implicate UVB.

APPENDIX D

PROTECTION FACTORS OF FABRICS

Clothing is an effective and reliable source of protection against solar UVR, provided consideration is given to the design of the garment and the UVR transmittance of the fabric. The garment should provide good coverage of the skin and the fabric should prevent most of the incident UVR from reaching the skin beneath it. It is not always possible for consumers to make a reliable assessment of the UVR protection of a fabric by visual inspection, so a method has been developed for determining the Ultraviolet Protection Factor (UPF) provided by a fabric, which is defined as a ratio of how much the effect of UV radiation is attenuated when UVR passed through fabric. This factor takes into account that different wavelengths of UVR have different effect on human skin and it is analogous to the Sun Protection Factor (SPF) quoted for sunscreens.

UPF of the fabric (EN 13758-1:2002) is given by:

$$UPF = \frac{\sum_{\lambda=290}^{\lambda=400} E(\lambda)\epsilon(\lambda)\Delta\lambda}{\sum_{\lambda=290}^{\lambda=400} E(\lambda)T(\lambda)\epsilon(\lambda)\Delta\lambda}$$

where λ is the wavelength of the radiation, $E(\lambda)$ is the spectral irradiance of the solar radiation at the Earth's surface, $\epsilon(\lambda)$ is the weighting function related to the reference erythral action spectrum published by the CIE (McKinlay and Diffey 1987), $T(\lambda)$ is the spectral transmittance of the fabric and $\Delta\lambda$ is the wavelength interval of the measurements.

A wide range of UPFs have been observed from different fabrics (Agnew et al 1998, Gies et al 1997a, Gies et al 1997b, Driscoll 2000, Khazova et al 2005, Khazova et al 2006a). Very light weight fabrics with an open structure often have UPFs of less than 5. By contrast, a heavier fabric with a closed structure, such as a knitted fabric containing elastane, may have a UPF above 50. Darker colored fabrics often absorb more UVR than lighter fabrics (Crews et al 1999), but the protection provided by a fabric cannot be reliably predicted from its color. UV protection factors specifically formulated for gloves have been developed and testing methodologies proposed (Khazova et al 2006b, 2006c, Khazova and O'Hagan 2006).

APPENDIX E

FACTS FOR INCLUSION IN INFORMATION LEAFLETS FOR OUTDOOR WORKERS

What is Solar UV Radiation? UVA is most abundant, can cause damage. UVB penetrates less deeply than UVA but is also damaging and is primarily responsible for sunburn. UVC is most hazardous but is absorbed by stratospheric ozone.

What are the Short Term Dangers? Skin reddening, sunburn, photokeratitis.

What are the Long Term Dangers? Immune system suppression, photoaging, skin cancer, outdoor workers have 6-8 times the risk compared to indoor workers. Risk is cumulative. Cutaneous Malignant Melanoma is the least prevalent skin cancer but has the greatest fatality risk (85% of all skin cancer deaths). For localized melanoma, the 5-year survival rate (U.S.) is 96%, but for regional- and distant-stage diseases the survival rates are 61% and 12%. Other longer-term risks include keratoses, photoconjunctivitis, cataract, and pterygium.

What are Skin Sensitizers? These include: medicines, dyes, wood preservatives, coal tar and pitch products, exposure to some plants and/or their juices, chlorinated hydrocarbons.

Who is at Risk? People at risk include those with fair skin, red hair, light colored eyes, large number of moles, atypical moles, large number of freckles, family/personal history of melanoma, history of severe sunburn early in life, chronic exposure to sun, family/personal history of non-melanoma skin cancer.

What are the Skin Phototypes? What are the various skin types, and which are at highest risk?

Skin Type Classification	Burns in the Sun	Tans after having been in the Sun
I. Melano-compromised	Always	Seldom
II.	Usually	Sometimes
III. Melano-competent	Sometimes	Usually
IV.	Seldom	Always
V. Melano-Protected	Naturally brown skin	
VI.	Naturally black skin	

What are the Environmental Risk Factors? More exposure risk at high altitudes, at reflective surfaces like sand, sea foam, concrete, fresh snow, unpainted corrugated steel, aluminum roofing.

When is the Risk at the Maximum? Risk is greater when the sun is high in the sky and your shadow is shorter than you height. This occurs in the four hours around midday in late spring and summer.

Protecting Workers from Ultraviolet Radiation

Protect Yourself:

- Limit exposure during the 3 hours (or 4-5 depending on latitude) around midday.
- Protect yourself even on cloudy days (clouds block visible radiation better than they block UVR and provides a false sense of protection).
- Work and take breaks in natural or artificial shade, including awnings, tents, screens, and canopies.
- Wear hats with a wide brim. Maybe with a hanging flap.
- Wear UV-resistant sunglasses with wraparound design.
- Keep your shirt on, especially at midday; loose fit clothes will allow air to circulate, use clothes to allow sweat to evaporate and keep the wearer cool.
- Use clothing, e.g. close-woven fabric, long-sleeved workshirt and jeans. Balance these issues with heat stress risk.
- Use sunscreens, SPF 15 or more, which protect against UVA and UVB, apply it at least 20 minutes before going outside, reapply after 2 hours.
- Use lip balms with SPF 15 or more.
- Know your skin's most vulnerable areas and keep them covered.
- Don't try to get a tan. A suntan indicates damage, not good health.
- Take care when you go on holiday, most people become complacent and receive excessive exposure.

How do sunscreens work? Sunscreens are chemicals that interact with the skin to protect it from the sun's rays.

What is the Global Solar UV Index (UVI)? The UVI indicates the relative hazard of the sun. Its use helps to plan outdoor activities.

Exposure Category	UVI Range
Low	<2
Moderate	3 to 5
High	6 to 7
Very High	8 to 10
Extreme	11 +

APPENDIX F

ICNIRP Guidelines on Limits of Exposure to Ultraviolet Radiation of Wavelengths Between 180 nm and 400 nm (Incoherent Optical Radiation) - Download at www.icnirp.org/pubOptical.htm.

APPENDIX G

Background information on the ICNIRP

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an independent scientific organization whose aims are to provide guidance and advice on the health hazards of non-ionizing radiation exposure and advance non-ionizing radiation protection for the benefit of people and the environment

To this aim, ICNIRP develops international guidelines on limits of exposure to non-ionizing radiations; provides guidance and recommendations on protection from non-ionizing radiation exposure; and establishes principles of non-ionizing radiation protection for formulating international and national protection programs.

ICNIRP's work scope covers all of the non-ionizing radiations including, the optical radiations (ultraviolet, visible and infrared - and lasers), static and time-varying electric and magnetic fields and radiofrequency (including microwave) radiation, and ultrasound.

ICNIRP communicates its views, advice and recommendations through publications, in the form of guidelines, statements, scientific reviews, proceedings of scientific meetings. Most of this information is available on its website, www.icnirp.org.

ICNIRP is the formally recognized non-governmental organization in non-ionizing radiation for the World Health Organization and the International Labour Organization, maintains a close liaison and working relationship with all international bodies engaged in the field of non-ionizing radiation protection, and represents radiation protection professionals worldwide through its close collaboration with the International Radiation Protection Association and its national societies.

Work is conducted in four standing committees - on Epidemiology, Biology, Physics and Engineering and Optical Radiation - and in conjunction with appropriate international and national experts and health and research organizations, universities and other academic institutions.

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