ICNIRP STATEMENT—PROTECTION OF WORKERS AGAINST ULTRAVIOLET RADIATION

International Commission on Non-Ionizing Radiation Protection*

INTRODUCTION

Occupational exposures to ultraviolet radiation (UVR) can originate from the sun and from artificial sources such as specialized lamps and open arcs processes, e.g., welding (Tenkate and Collins 1997; Hietanen and von Nandelstadh 1998). Although indoor workers are normally protected by clothing and eyewear, the same level of protection is not generally achieved for outdoor workers. Most often, over-exposures of indoor workers arise from accidental failures of safety measures or protective equipment. Outdoor workers receive significant exposure to solar UVR and are thereby at increased risk of suffering the adverse consequences associated with excessive 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 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 UVR-related eye diseases.

Exposure guidelines for UVR have been adopted by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) based upon earlier recommendations of the International Radiation Protection Association and the American Conference of Governmental Industrial Hygienists (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 European Union has published a document on protection of the worker against health hazards from UVR (European Commission 2006). The sun position and the geometry of exposure determine the irradiance on the eye and skin. 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 training and awareness.

At any given latitude, occupational exposures can be classified into two broad groups: high- and low-level exposures. Workers in the construction industry, recreation workers (e.g., ski resort guides and lifeguards), agricultural and horticultural workers, and fishermen generally belong to the high-level group while workers who are mainly indoors or only sometimes outdoors including teachers, police officers, delivery persons, and military staff are generally exposed to low levels of UVR, though this may vary as a result of recreational pursuits. When appropriate, outdoor workers should be supplied with personal protection items, such as hats (Diffey and Cheeseman 1992), sunglasses (Sliney 2005), protective clothing (Osterwalder and Rohwer 2002), and sunscreens (FDA 1978; Gallagher 2005b). For a sun-sensitive worker, the difficulties of achieving sufficient reduction of solar UVR exposure for compliance with guidelines (Gottlieb et al. 1997; Azurdia et al. 1999) may lead these individuals not to choose outdoor occupations. In temperate climates, the potential exposure of outdoor workers varies greatly with season.

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 photo curing equipment.

BACKGROUND

UVR comprises the shorter wavelengths, highest photon energy, of the part of the spectrum that is

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classified as optical radiation. The spectrum of UVR extends between ionizing soft x rays and visible radiation. Effects of UVR share some aspects of effects of ionizing radiation, e.g., a direct photon effect upon DNA. The UVR spectrum is frequently divided into three photobiological spectral bands (CIE 1987) (Fig. 1).

The Commission International de L'Eclairage (CIE) designated UVR spectral bands are UV-C (100–280 nm), UV-B (280–315 nm), and UV-A (315–400 nm).

Terrestrial solar UVR consists mainly of UV-A and UV-B radiation. Only artificial light sources emit radiant energy within the UV-C spectral band. The dosimetry of UVR exposure of the eye and skin requires the use of several radiometric quantities and units. The *irradiance* (W m^{-2}) is the surface exposure dose rate in watts per square meter, and the *radiant exposure* (J m^{-2}) is the accumulated radiant energy per unit area in joules per square meter.

The *radiant power* (W) is the rate of energy output of an optical source (W = J s^{-1}). The related photometric quantity *luminous flux* (lm) describes the rate of energy output of a light source weighted for the sensitivity of the eye, thus related to the visual perception associated with a defined radiant power. For a pulsed light source such as a flash lamp, the "radiant energy" in joules (J) describes the energy output, 1 J corresponding to 1 watt delivered over 1 s or 1 watt-second.

BIOLOGICAL EFFECTS

UVR induced biological effects upon the skin and eye can occur in the work environment without being recognized (Passchier 1987). Hence, an understanding of the potential biological effects is essential. In photobiology, the concept of a biologically effective dose is of critical importance. The UVR *action spectrum,* $S(\lambda)$ (Fig. 2), is used to define the relative effectiveness of different wavelengths for a given effect. The *biologically effective irradiance*, E_{eff}, (W m^{-2}), is calculated by spectrally weighting the *irradiance* with the action spectrum of the biological response. Mathematically, this is done by multiplying the spectral irradiance for each wavelength interval, E_λ (W m^{-2} nm^{-1}), with the relative biological response at the same waveband, $S(\lambda)$, across the relevant spectrum and then adding up all irradiance components

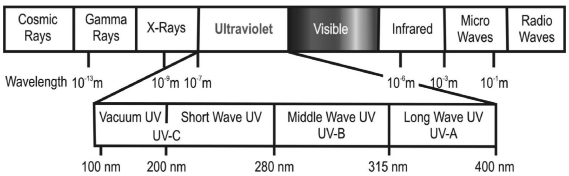

Fig. 1. The ultraviolet spectrum and the wavelength bands.

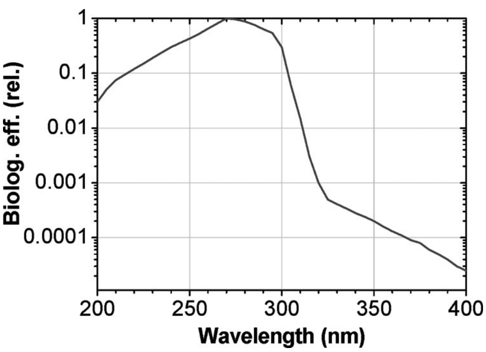

Fig. 2. Relative spectral effectiveness of UVR (ICNIRP 2004).

for the different spectral components. The effective radiant exposure, H_{eff} (J m^{-2}), is the biologically efficient irradiance multiplied with the exposure time.

The target molecule for a given effect is termed the *chromophore*, and while there are many photochemically active chromophores in the skin and eye, a key chromophore for delayed effects is DNA (UNEP et al. 1994).

Absorption by biological tissues

UVR is absorbed by all constituents of living organisms. Interactions with biomolecules will result in absorption of specific wavelengths and result in production of excited states. The peak absorption of DNA occurs around 260 nm with a sharp drop in absorption through the UV-B range (several orders of magnitude). No absorption is detected for wavelengths longer than around 325 nm.

Aromatic amino acids, like tryptophan, absorb in the UV-B and extend into the UV-A range (UNEP et al. 1994). DNA strand breaks are induced by UV-B and UV-A (Beissert and Loser 2008; Ridley et al. 2009).

The absorption of UVR may be photosensitized by oxygen. Also, absorption of UV-A may result in DNA-protein cross-links, and in general, 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.

Skin effects

Upon UVR irradiation of the skin, several signaling substances (cytokines) are liberated or activated or synthesized by keratinocytes. These cytokines exert various effects; most notably they cause inflammatory reactions (Norval 2006; Norval et al. 2008) in the skin or eyes and in the body, e.g., fever. Some cytokines regulate growth, differentiation or death of skin cells, and some activate pigment cells (melanocytes), which darkens the skin with newly formed melanin pigments (melanogenesis), commonly called tanning.

Acute effects on the skin

"Sunburn" follows excessive exposure to UVR and is the result of a phototoxic effect in the skin unlike other types of "burns" (Fitzpatrick 1975; Hawk and Parrish 1982). Sunburn (the skin redness or "erythema") is rarely detected before four hours, and reaches a maximum at about 8–12 h 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 (Olson et al. 1966). Higher doses may result in pain and skin swelling (edema), and a delayed cell killing (apoptosis) after 24 h may subsequently leave extensively vacated layers of cells moving outward and into the horny layer (or stratum corneum), the outermost layer of the skin, causing peeling after a few days, or with more acute damage by massive cell disintegration (necrosis) blisters may even arise very rapidly. Sunburn sensitivity varies substantially with skin complexion and color, and this is reflected in the solar exposure time required to induce a minimal sunburn reaction; e.g., 15–30 min of sun exposure for fair skin, 1–2 h of exposure for moderately pigmented skin. For comparison, darkly pigmented skin may not clearly show sunburn even after a full day exposure. Frequently individuals are grouped into 1 of 6 sun-reactive skin types, and these skin types fall into three more significant groups based upon how well individuals produce the pigment, melanin (Morison 1985), in their skin (Table 1) (Parrish 1982; Diffey 1994; CIE 1998).

Specialized measurement quantities have been developed by dermatologists to describe sunburn sensitivity. The *Minimum Erythemal Dose* (MED) is defined as the UVR exposure that will produce a just-perceptible erythema 8–24 h after irradiation of the skin of one individual. The MED varies with the spectrum of the source of the UVR, the tanning capacity of the individual, and any prior adaptation that individual had from previous exposures. Because an MED refers a specific individual, there also exists a related, standardized unit called the *Standard Erythemal Dose* (SED) to quantify the ability of a source to produce erythema (McKinlay and Diffey 1987): 1 SED equals 100 J m^{-2} of erythemal effective UVR exposure (i.e., spectrally weighted with the CIE erythemal action spectrum). This unit is correspondingly widely used in *erythemally effective irradiances* (in W m^{-2} eff or SED h^{-1}). Still another, related quantity is the *UV Index* used in public health to describe the risk of sunburn at given meteorological conditions. A UV Index of 1.0 corresponds to slightly less than 1 SED per hour (it is precisely 0.025 W m^{-2} eff or 0.9 SED h^{-1}). Both units, SED and UV Index, are standardized by CIE (CIE 1998).

The wide range of susceptibility to solar exposure among phototypes (Table 1) largely corresponds with two types of melanin produced by melanocytes: eumelanin (dark brown-black) and phaeomelanin (yellow-red) (Hönigsmann et al. 1986; Césarini 1988; Young 1994, 2004). Phaeomelanin absorbs UVR photons and with overexposure produces reactive oxygen species (ROS) which are phototoxic (Fitzpatrick and Szabo 1983). Eumelanin, a stable free radical, absorbs UVR photons and scavenges free radicals and is photoprotective (Pathak and Faneslow 1983). All individuals produce eumelanin and phaeomelanin in different ratios according to genetic makeup and as a consequence present large differences in solar sensitivity and skin cancer incidence (Rosen et al. 1990). In addition, darker skin types have more efficiently inducible DNA repair than the skin phototypes I and II (Sheehan et al. 2002; Nan 2009).

Skin adaptation from frequent UVR exposure is not only the obvious effect of skin darkening, "tanning" or "melanogenesis," but also of "skin thickening," or rather thickening, hyperplasia of epidermis, the outer epithelial layer of skin (Bruls et al. 1984) (Table 2).

Table 2. Skin phototypes and average threshold exposure. MED_1 expressed in SED_2 for sunburn with and without adaptation.

Skin phototype	Individual MED without adaptation	Individual MED with adaptation[a]
I–II (Celtic)	2 SED[b]	5 SED
III–IV (Mediterranean)	5 SED	12 SED
V (Asians)	10 SED	60 SED
VI (Black)	15 SED	80 SED

[a] MED, Minimal Erythema Dose. Minimal Erythema Dose with adaptation implies three weeks of tanning from solar exposure without erythema.
[b] SED, Standard Erythema Dose. The ranges of SEDs are not prescriptive but only indicative of an MED with a large spread of values for each phototype.

Table 1. Classification of skin types based on their susceptibility to sunburn in sunlight and their ability to tan.

Skin phototype	Sun sensitivity	Sunburn susceptibility[a]	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

[a] SED, standard erythemal dose.

This thickening of the outermost layers of the skin may serve as an adaptation to UV-B exposure (Bech-Thomsen and Wulf 1996). There can be a 3- to 5-fold thickening of the stratum corneum within 1 to 7 wk after several exposures to UV-B, returning to normal thickness about 1 to 2 mo after ceasing the exposure. Since attenuation is exponentially related to thickness, thickening of the stratum corneum as a result of sun exposure is associated with an increase in UVR protection. In lightly pigmented skin types, thickening is probably more important than tanning in providing protection. However, in darkly pigmented individuals the opposite is probably true (Beitner and Wennersten 1985). Although a tanned skin does confer a degree of protection (Kaidbey and Kligman 1978), this may be no more than a factor of two to three in the absence of skin thickening. As already mentioned above, the mode of protection by melanin is not purely optical, but it importantly involves chemical protection by scavenging ROS generated by the UV irradiation. Aside from epidermal thickening and tanning, a basic shift in cytokines in the skin may also strongly contribute to the adaptation of the skin, notably an increase in interleukin-1 receptor antagonist (Hirao et al. 1996).

The wavelengths that induce tanning are very similar to those producing erythema (Fig. 2). Subjects with sun-reactive, melano-compromised skin (Type I and II; Table 2) are poor tanners compared to those with melano-competent skin (Type III and IV; Table 2) who tan well. Melanogenesis can be stimulated in individuals who tan well, with solar UVR doses that are considerably below the erythemal doses in the UV-A region (Sheehan et al. 2002).

Photosensitizers and the working environment

In addition to a direct detrimental effect of the absorbed UVR-photon on a cell constituent, a phototoxic reaction may be mediated by a chromophore that after absorbing the photon exerts a detrimental effect on a vital cell constituent.

Some chemicals can thus sensitize the skin to UVR (most notably, UV-A); the process is termed *photosensitization* and the chemical a *photosensitizer* (Willis 1988). A photosensitized reaction is proportional to the concentration of the photosensitizer and to the magnitude of the UVR exposure dose. Photosensitizing molecules may be endogenic, produced by the body, or may be exogenic, introduced into the body from the outside. Exogenic photosensitizers (Table 3) can enter the skin from the surface or from the blood, originating from any other route into the body.

Exogenic photosensitizers (Table 3) can be found in domestic work environments, outdoor workplaces, and in industrial working places. In addition, the strongest photosensitizers are often administered for medical purposes, and workers exposed to UVR should be aware of this potential. Certain occupations may encounter specific photosensitizers. For example, dyes are encountered in the textile industry, photosensitizing plants are encountered in agriculture, and some inks found in the printing industry may contain a photosensitizer (e.g., amyldimethylaminobenzoate). Roofers and road workers encounter coal tars that are photosensitizers.

Some individuals who have been exposed to photosensitizers and have experienced a phototoxic reaction may present permanent skin reactions when exposed only to the sun. These individuals are referred to as *chronic photo-reactors*.

Some phototoxic agents can stimulate an immunological reaction. These substances are *photo-allergens*. The magnitude of a photoallergic reaction depends only on the amplitude of the immunologic reaction, and can be recognized by spreading of the photoallergic reaction beyond the exposed skin.

Reactions revealing chemical photosensitivity

Clinical investigations and the use of a battery of tests are normally required to identify with precision the origin of abnormal skin reactions. An exaggerated sunburn reaction is associated with a number of systemic drugs (Table 3), but typically with moderate doses of demethylchlortetracycline or high doses of other tetracyclines such as doxycycline and chloropromazine. For example, UV-A exposures that are normally harmless may produce mild sunburns, and UV-B exposures that would normally produce a just-perceptible erythema may result in severe reactions.

Coal tar, pitch, and a number of their constituents, combined with exposure to sunlight, produce immediate prickling or burning sensations in the exposed skin. Longer exposure to sunlight increases the intensity of the "pitch smarts" and produce erythema as well and a wheal and flare reaction. Late onset hyperpigmentation can also result and appear in bizarre patterns if due to splashing (e.g., with wood preservatives). Finally, blistering reactions may occur from UVR photosensitization that is most typical of contact with plant psoralens. The reaction is triggered by contact with the sap from a psoralen containing plant and subsequent 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 and may coalesce to produce a localized surface pattern sometimes reproducing leaf imprints, but subside within days. Pigmentation abnormalities may develop and persist for months. The intensity of erythema and blistering depends

Table 3. Photosensitizers in the work environment.

Sources	Active ingredients
A. Photosensitizers in the domestic work environment	
Bacteriostats in soaps	Halogenated salicyclanilides
Wood preservatives	Creosote
Vegetables	Psoralens in celery and parsnips
Perfumes and cosmetics	5-methoxypsoralen (Bergapten) in oil of Bergamot, musk ambrette, 6-ethylcoumarin
Sunscreens	p-aminobenzoic acid (PABA), ethoxyethyl-p-methoxycinnamate, isopropyldibenzoylmethane, butylmethoxydibenzoylmethane
Disinfectants and antiseptics	Methylene blue, eosin and rose bengal
Tattoos	Cadmium sulphide
B. Photosensitizers in the outdoor work environment	
Plants	Furocoumarins: psoralen, 8-methoxypsoralen, 5-methoxypsoralen, pimpinellin, sphondin, angelicin
Umbelliferae	
Giant hogweed (*Heracleum mantegazzianum*)	
Cow parsnip (*Heracleum sphondylium*)	
Wild parsnip (*Pastinaca sativa*)	
Tromso palm (*Heracleum laciniatum*)	
Rutaceae	
Common rue (*Ruta graveolens*)	
Gas plant (*Dictamnus alba*)	
Bergamot orange (*Citrus bergamia*)	
Moraceae	
Fig (*Ficus carica*)	
C. Photosensitizers in the industrial/working environment	
Anthraquinone based dyes	Benzanthrone; Disperse Blue 35
Polycyclic hydrocarbons	Pitch, coal tar, wood preservatives, anthracene, fluoranthrene
Drugs	Chlorpromazine, amiodarone
Printing ink	Amyl-o-dimethylaminobenzoic acid
Animal feed supplement	Quinoxaline-n-dioxide
D. Major photosensitizers administered for medical purposes	
Drugs	
Antibacterial	Tetracyclines, sulphonamides, nalidixic acid, 4-quinolones
Tranquilizer	Phenothiazines (chloromazine)
Antidepressant	Protryptiline
Diuretic	Chlorthiazides, frusemide
Antiarrhythmic	Amiodarone, methyldopa, quindine, propranolol
Anti-inflammatory	Ibuprofen, azapropazone, naproxen
Antifungal	Grizeofulvin
Bacteriostat	Halogenated salycilanilides, bithionol, buclosamide
Topical antifungal	Fentichlor, hexachlorophene
Antimalaric	Quinine
Photo therapies	
Photochemotherapy	8-methoxypsoralen, 5-methoxypsoralen, trimethylpsoralen, khellin
Photodynamic therapy	Photofrin II

on UVR radiant 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.

Chronic effects—accelerated skin aging and skin cancers

Photo-aging 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 (Kligman and Kligman 1986; Leyden 1990; Kligman and Sayre 1991; Karagas and Zens 2007). These characteristics reflect profound structural changes in the dermis. It is not entirely clear which wavelengths are most responsible for photo-aging, but some research studies point to solar UV-A (Fourtainier 1989; Trautinger 2001).

Skin cancers

The three common forms of skin cancer, listed in descending order of incidence and ascending order of severity, are basal cell carcinoma, squamous cell carcinoma, and malignant melanoma (Armstrong and Kricker 1993, 1994, 1996). Around 90% of skin cancer cases are of the non-melanoma variety with basal cell carcinoma being approximately four to eight times, depending on latitude, as common as squamous cell carcinoma (Gallagher et al. 1995a). Exposure to UVR is considered to be a major etiological factor for all three forms of cancer (Elwood et al. 1985; Green 1990; IARC 1992; Horn et al.

1994). For basal cell carcinoma and malignant melanoma, neither the wavelengths involved nor the exposure pattern that results in risk have been established with certainty (Setlow et al. 1993); whereas for squamous cell carcinoma, both UV-B and UV-A are implicated and the major risk factors seem to be cumulative lifetime exposure to UVR and a poor tanning response (Gallagher et al. 1995b). The risk of developing skin cancer varies greatly with skin type (Table 2). Therefore, persons who readily sunburn are also more prone to develop skin cancer. Indeed, a history of severe sunburns, as more typically occur in periodic recreational exposure, is a risk factor for malignant melanoma. Precursor lesions of squamous cell carcinoma known as actinic keratoses are common in fair-skinned outdoor workers by the age of 50 to 60 y, depending upon latitude. Currently, the contribution of UV-A is considered as dangerous as the contribution of UV-B for inducing all forms of skin cancers considering the far greater amount of UV-A compared to the UV-B in the normal solar exposure (de Gruijl and van der Leun 1994). Current evidence suggests that for melanoma and basal cell carcinoma, UVR exposure early in life (before working age) seems to be important (Gallagher 2005a and b). However, cumulative exposures are without doubt responsible for some forms of melanoma (Swerdlow and Weinstock 1998; Veierod et al. 2003). A recent mouse model mimicking the most frequent human melanoma demonstrated the critical role of UV-B delivered shortly after birth and apparent absence of efficacy of UV-A (De Fabo et al. 2004).

Ocular effects

Exposure of the eye to UVR is associated with a variety of disorders, including damage to the eyelids, cornea, lens, and perhaps the retina (Zuclich 1989). Ocular exposure to UVR is far more affected by the geometry of exposure than is skin exposure. The brow ridge and lids strongly protect the eye from UVR from most directions. During squinting or closure of the eye, the upper and lower eyelids protect a portion or the entire eye from UVR exposure (Sliney 2005). The ocular media partially transmit and refract UVR. The refraction may concentrate directly incident radiation to a higher irradiance (Coroneo 1990) (Fig. 3). Therefore, ocular effects of the sun are primarily located in the lower nasal part of the outer eye (Sasaki et al. 2003).

The UVR reaching internal structures of the eye is attenuated depending upon the wavelength of incident radiation (Fig. 4).

Wavelengths shorter than 290 nm are almost entirely attenuated by the cornea. 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 a UVR absorbing lens or if there is no lens, i.e., aphakia after cataract operation, which is currently quite rare, a significant fraction of the incident UVR may reach the retina. Special exposure limits are applied for these rare individuals or in the International Organization for Standardization (ISO) ophthalmic safety standard ISO 15004-2:2007.

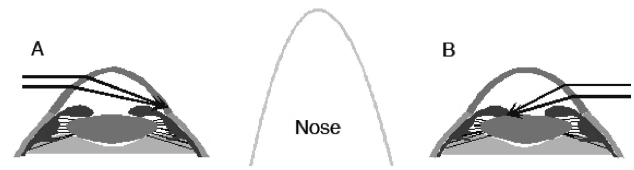

Fig. 3. Concentration of UVR in the eye by refraction, the Coroneo Effect (Coroneo 1990).

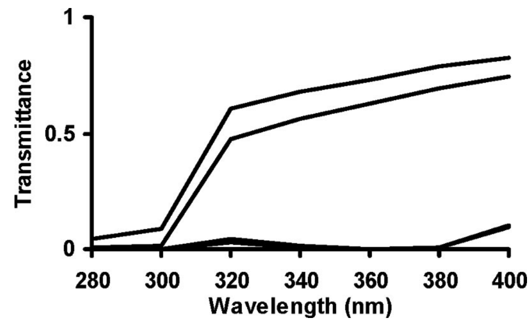

Fig. 4. UVR transmittance of the human eye (Boettner and Wolter 1962). The lines show from above the transmittance of UV-A and UV-B to the back surface of the cornea, the front surface of the lens, the back surface of the lens, and to the surface of the retina.

The cornea does not adapt to repeated exposures as much as the skin, but some thickening of the epithelium and other changes may take place with seasons (Ringvold et al. 2003). Since the transparent media of the eye, as a contrast to skin, do not have any melanin pigment, there is no correlation between the UVR sensitivity of the eye and skin type. An unprotected eye exposed to UVR from sunlight reflected from light sand or snow during one day may accumulate a sufficient dose to cause an adverse effect in the cornea and conjunctiva of the eye known as photokeratoconjunctivitis. 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 of symptoms from a feeling of itchiness, "sand in the eye" sensation, and increased tearing, to severe pain and photophobia, light sensitivity, which is associated with a swelling and loss of the superficial cells in the cornea and the conjunctiva. Within 24–48 h, the pain decreases, and the light sensitivity disappears due to re-epithelialization of the corneal surface. This condition is popularly referred to as "snow blindness" or "welder's flash."

In addition to corneal injury, laboratory studies have demonstrated acute cataract formation from UVR at wavelengths shorter than 310 nm emitted by artificial or laser sources (Pitts et al. 1977; Hockwin et al. 2002; Söderberg et al. 2002; Dong et al. 2005, 2007). 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 (Ham et al. 1982; Zuclich 1989).

Several adverse ocular effects appear to be related to chronic UVR exposure. For example, pterygium, an in-growth over the surface of the cornea of tissue similar to conjunctiva, has been associated with chronic exposure to UVR (Lim et al. 1998; McCarty and Taylor 2000). As pterygium progresses, the in-growth can cover the cornea and severely impair vision. In addition, pingueculum, which is a non-malignant connective tissue tumor in the conjunctiva, has been attributed to life-long exposure to UVR. Droplet keratopathy is a focal deposition of lipids in the cornea with an adverse effect on transparency and also has been epidemiologically associated with exposure to UVR (Taylor et al. 1992; Lim et al. 1998). Perhaps, most importantly, the time of onset of some cataracts, which is a clouding of the lens that disturbs vision, is accelerated. Cataract is part of the natural aging process of the eye. At least one type of cataract, namely cortical cataract, is associated with UVB exposure from the sun (Taylor et al. 1988; Italian-American Cataract Study Group 1991; Leske et al. 1991; McCarty et al. 2000; McCarty 2002; Sasaki et al. 2003), but experts disagree on the degree of importance played by environmental solar UVR exposure compared to ambient temperature (Sliney 2002a).

Some epidemiological studies have indicated that blue light may be toxic to the retina but the epidemiological evidence is not conclusive (Taylor et al. 1992).

Systemic effects

The best-established beneficial effect of solar UVR on the skin is the synthesis of vitamin D_3 by UVB (Webb and Holick 1988; Webb et al. 1989). Sunlight regulates and limits further production of vitamin D_3 in the skin to preclude a toxic level (Preece et al. 1975). Only brief daily sub-erythemal exposures to sunlight are required to synthesize the minimum daily requirement for vitamin D_3. Vitamin D is known to be essential for the body's proper uptake of calcium, which is important for healthy bones. Some scientific hypotheses have been proposed that higher levels of solar UVR exposure through vitamin D synthesis appear to correlate with lower risks of internal cancers; however, this theory generally has not been substantiated (ICNIRP 2006; IARC 2008).

Exposure to UVR may also cause systemic immunologic effects which may be detrimental to a healthy person (aggravating infections or allowing skin cancers to grow) or used therapeutically on skin diseases, most notably psoriasis (de Gruijl 2008).

OCCUPATIONAL EXPOSURE LIMITS AND UV SAFETY STANDARDS

Occupational health and safety guidelines, regulations and standards have been developed in several countries and by international organizations to protect workers 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. There is some controversy over the balance of health benefits from UVR exposure and the risks associated with skin cancer. The variability of the susceptibility to skin cancer by individuals with differing skin types poses a challenge in establishing an exposure guideline for all. The two most widely used guidelines are virtually identical. Both the ICNIRP (ICNIRP 2004) and the American Conference of Governmental Industrial Hygienists (ACGIH 2009) 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 (Table 2).

The effective irradiance, E_{eff} (μW cm^{-2} or W m^{-2}), is obtained by weighting the spectral irradiance, E_λ (μW cm^{-2} nm^{-1} or W m^{-2} nm^{-1}), against the UVR action spectrum $S(\lambda)$ (rel.), for each wavelength interval, $\Delta\lambda$ (nm), within the wavelength range 180 nm to 400 nm (eqn 1):

$$E_{eff} = \Sigma E_\lambda S(\lambda)\Delta\lambda. \quad (1)$$

The ICNIRP guideline for maximum human biologically efficient radiant exposure of the eye and skin to UVR within an 8 h (30,000 s) period is 30 J m^{-2} (3 mJ cm^{-2}) effective (ICNIRP 2004).

If the irradiance is constant, the permissible exposure duration, t_{max} (s) is the ICNIRP exposure limit of 30 J m^{-2} divided by the effective irradiance (eqn 2):

$$t_{max}\ (s) = \frac{30\ J\ m^{-2}}{E_{eff}\ (W\ m^{-2})} \text{ or } t_{max}\ (s) = \frac{3\ mJ\ cm^{-2}}{E_{eff}\ (mW\ cm^{-2})}. \quad (2)$$

In addition to the above requirement, following the ICNIRP guidelines (ICNIRP 2004), the ocular exposure is also limited to unweighted UV-A, 10,000 J m^{-2} (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 UV-A needs to be evaluated against both the limits of UV-A 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.

The UV-A irradiance, E_{uva} (W m^{-2}), in the UV-A spectral region is the spectral irradiance at each wavelength interval summed from 315 nm to 400 nm (eqn 3):

$$E_{uva} = \Sigma E_\lambda \times \Delta\lambda. \quad (3)$$

For constant irradiance, the maximum duration of exposure related to the UV-A limit can estimated as the ratio between the unweighted UV-A ICNIRP guideline and the UV-A irradiance (eqn 4):

$$t_{max}\ (s) = \frac{10\ kJ\ m^{-2}}{E_{uva}\ W\ m^{-2}} \text{ or } t_{max}\ (s) = \frac{1\ J\ cm^{-2}}{E_{uva}\ W\ cm^{-2}}. \quad (4)$$

ACGIH applies the UVA limit expressed as a total radiant exposure only up to 1,000 s (16.7 min), and limits the total irradiance to 10 W m^{-2} (1 mW cm^{-2}) for periods greater than 1,000 s. It follows that for continuous 8 h exposure, the radiant exposure limit of 10,000 J m^{-2} (1 J cm^{-2}) is equivalent to 10 W m^{-2} (1m W cm^{-2}) following the ACGIH guidelines (ACGIH 2009) and to 0.33 W m^{-2} (33 μW m^{-2}) following the ICNIRP guideline (ICNIRP 2004).

Application of the ICNIRP limit for the skin

In terms of acute skin effects from solar exposure, the ICNIRP guideline for maximum human biologically efficient radiant exposure of the eye and skin to UVR of 30 J m^{-1} 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 erythemal effectiveness curve (CIE 1998). For a germicidal lamp, the exposure limit of 30 J m^{-1} is approximately equivalent to 10 SED. At this level, detectable molecular damage appears to be fully repaired within a 24 h period. For the case of continuous exposure for longer than 8 h, such as is possible for a 10–12 h extended shift (or even a double shift) for indoor workers, special care needs to be taken. The exposure guideline is based on a normal 24 h light/dark cycle where cellular repair can take place after the exposure is discontinued.

Application of the ICNIRP limit for the eye

The human eye is, to a very large extent, naturally protected from overhead exposure to solar UVR in the outdoor environment. In the indoor environment, the eye is similarly less susceptible to UVR exposure from overhead sources, but very susceptible to sources directly within the normal field-of-view, such as a welding arc. 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 (ICNIRP 2004) specify limited angular acceptance for such assessments. In both indoor and outdoor environments, it would be inappropriate to use horizontal UVR irradiance only to assess risk.

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 measured exposure level. Except for laser exposure, highly localized exposure is generally not encountered. The ICNIRP guideline (ICNIRP 2004) specifies that in no case the irradiance is 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 cosine dependence, a detector is required which features a good cosine response 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 FOV, acceptance angle, can be reduced and limited to 80° (±40° from the normal) (ICNIRP 2007).

CIE/IEC risk groups for lamps

American National Standards Institute (ANSI) has produced a technical standard for lamps and lamp systems in order to indicate the potential photobiological risk posed by lamps (ANSI/IESNA 2007). This standard

Table 4. IEC lamp risk groups.[a]

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

[a] NOTE: The IEC (IEC 2006) exempt group regarding the un-weighted UVA limit was based on the ACGIH integration duration of 1,000 s (ACGIH 2009) and exposure to such lamps from a distance of 20 cm for longer than 16 min might lead to exposures above the limit as recommended by ICNIRP, where the integration duration is 8 h.

was also adopted by the International Electrotechnical Commission (IEC) as IEC62471:2006, identical to CIE S009 (CIE 2006a), and was developed as a manufacturer's standard to specify risk groups, which are to be assigned to the lamp by the manufacturer.

The risk group definitions are based on varying maximum permissible exposure durations (Table 4).

Thus, for the exempt group, effective exposure at the reference distance, for specialized UVR lamps 20 cm, to the lamp is below the UVR exposure limit for the eye for 8 h. For Risk Group 3, the UVR exposure limit at 20 cm is exceeded in times shorter than 1,000 s or about 16 min. Lamp Risk Groups are not only based on the UVR limit, but on all relevant exposure limits, as shown in Table 4, 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.

Two different distances of measurement are defined in the standard for the risk group classification depending on the intended use: the distance where the luminance level equals 500 lux for general lighting service lamps and 20 cm for non-general lighting service lamps. 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.

OUTDOOR WORKERS—OCCUPATIONAL EXPOSURE TO SUNLIGHT

Solar ultraviolet radiation

The ultraviolet component of the terrestrial solar spectrum accounts for only about 5% of the radiant energy, but this component is largely responsible for the deleterious effects of solar exposure (Fig. 5) (Madronich 1993).

Note that UVR of wavelengths shorter than 290 nm does not penetrate beneath the ozone layer of the Earth's atmosphere.

Both the *quality* (spectrum) and *quantity* (irradiance) of terrestrial UVR varies with the elevation angle of the sun above the horizon, complementary of the solar zenith angle or the angle below zenith (Table 5).

These solar angles depend on the time of day, day of the year, and geographical latitude. The quality and quantity of solar UVR are greatly modified by the atmospheric path. Clouds redistribute and generally reduce the UVR reaching the Earth's surface, but often not nearly as much as the average person would expect, as sunburns can occur on overcast days. The water vapor in clouds strongly absorbs solar infrared radiation (IRR) far more than ultraviolet wavelengths. Overexposure to

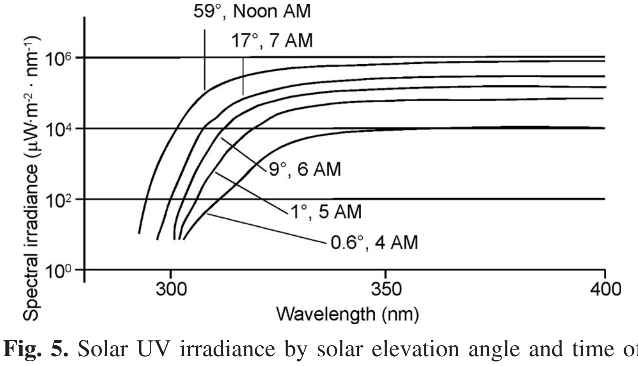

Fig. 5. Solar UV irradiance by solar elevation angle and time of day, 18 June 2000, Chilton, UK, detector perpendicular to earth surface. (Modified from UK Health Protection Agency.)

Table 5. Measured ICNIRP effective UVB from the sky with a 40° cone field of view.

Sky conditions location, elevation	Zenith reading (μW cm^{-2} sr^{-1})	Directly at sun (μW cm^{-2} sr^{-1})		Opposite sun (μW cm^{-2} sr^{-1})	Horizon sky (μW cm^{-2} 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 2,750 m	0.54	1.6	Z = 25°	0.82	0.08

UVR may therefore increase because of reduced warning sensation due to absence of IRR. Light clouds scattered over a blue sky make little difference to UVR irradiance unless directly covering the sun, whereas a light overcast may reduce terrestrial UVR to less than one-half of that from a clear sky; and, more importantly, a light overcast or conditions of partial cloudiness generally redistributes more UVR to the horizon sky, thereby increasing eye exposure (Sliney 1986). Even with heavy cloud cover the scattered ultraviolet component of sunlight, diffuse UVR, is seldom less than 10% of that under clear sky. Only heavy storm clouds can virtually eliminate terrestrial UVR. Altitude plays some role since the thickness of the cloud layer is greater in valleys than in high mountains. Although less attenuation of UVR may occur at high altitude, air pollution and ozone concentration may mask this net change due to altitude alone.

Reflection of solar UVR from the ground and work surfaces such as snow, sand and certain types of concrete and copper roofing plays an important role adding to the direct exposure. Most urban ground surfaces reflect of the order of 10%, grass of the order of 1%, and fresh snow nearly 90%. Water reflects both the direct UVR from the sun as well as the diffuse component from the entire sky. Hence, for a person working over open water, 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 (Table 6).

Human solar exposure

Humans have evolved in sunlight, and therefore adapted in several ways to natural conditions of sun exposure. By contrast, exposures from many types of artificial sources such as welding arcs may bypass these adaptations. Anatomical and behavioral factors tend to reduce the severity of sunlight exposure. Hence, occupational exposure to sunlight is treated in this separate section. UVR exposure of an individual depends upon four primary factors: the ambient solar UVR, the fraction of ambient exposure received on different anatomical sites, the behavior of the individual, and the duration spent outdoors. Thus, hazard assessment for specific outdoor work environments can only be semi-quantitative. A study of the work site and tasks can provide an indication of individual worker exposure (Gies et al. 1995; Diffey et al. 1996; Thieden et al. 2001, 2004, 2005; Glanz et al. 2007; Knuschke et al. 2007).

The role of site-specific measurements in this scheme is limited, since exposure will vary so much with time of day and season. In this regard, the UV Index (WHO et al. 2002) available from regional sources may be useful to establish baseline exposure values (Table 7).

Table 6. Reflectance of ICNIRP effective solar UVB from terrain surfaces.[a]

Terrain surfaces	Diffuse reflectance ICNIRP effective solar UVB %
Green mountain grassland	0.8–1.6
Dry grassland	2.0–3.7
Wooden boat dock	6.4
Black asphalt	5–9.0
Concrete pavement	8–12
Atlantic beach sand (dry)	15–18
Atlantic beach sand (wet)	7
Above open water (large lakes, wide rivers, ocean)	18–22
Sea foam (surf)	25–30
Glass-covered building	5–40 (specular—angle-dependent)
Aluminum structures	50 (up to 90 if polished)
Dirty snow	59
Fresh snow	88

[a] Adapted from Sliney (1986).

Table 7. The Global UV Index.[a]

Exposure category	UV Index range
Low	<2
Moderate	3 to 5
High	6 to 7
Very high	8 to 10
Extreme	11+

[a] Adapted from WHO et al. (2002).

Several methods of reducing personal exposure to solar UVR are available. The UVR exposure of the eye and skin can be modified by the use of personal protective equipment such as sunglasses (CEN 1997), goggles, hats, clothing (Robson and Diffey 1990; British Standard 1998), and sunscreens (Stenberg and Larkö 1985; Rhodes and Diffey 1996). The ambient UVR is sometimes monitored in an outdoor work environment. For research studies, UVR sensitive dosimeters, e.g., film badges, have been used. All three methods, individually or in combination, have been employed for data acquisition and for modeling in research studies (Gies et al. 1992, 1995, 1997).

Such studies show that indoor workers, as with most of the population, may typically experience about 300 SED per year from solar exposure (mostly from weekends and holidays). Outdoor workers at the same latitudes receive about 3 to 5 times these exposure doses, certainly in excess of 1,000 SED per year. Ocular exposure rarely exceeds the ICNIRP guideline (ICNIRP 2004) for daily exposure except in unusual conditions, e.g., reflections over snow. Work practices generally are based upon experience and recognition of different levels of protection required by seasonal changes in the ambient UVR (Fig. 6).

The relative effective UVR 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 UV-B irradiance is reduced by cloud cover, the actual UV-B dose rate to the eye from the sky scatter may actually increase or is at least hardly reduced (Sliney 1994a, 1995). 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 (Pitts et al. 1977; Passchier 1987), acute corneal injury is not often experienced because of the protection by the upper lid and brow and by behavioral avoidance of direct sunlight exposure of the eye (Sliney 2002b). Individuals do not look directly overhead when the sun is very hazardous to view, whereas most people may stare at the sunset when the sun is comfortable (and safe) to observe near the horizon. 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 can therefore be very different from exposures from the sun.

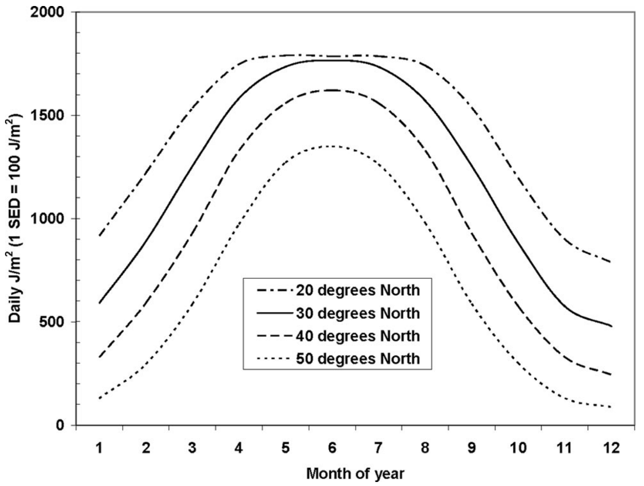

Fig. 6. Seasonal variation in daily erythemal exposure for four latitudes, assuming a 2 h midday exposure. An exposure of 1 SED is approximately the ICNIRP guideline for a daily exposure limit (adapted from Sliney and Wengratis 2006).

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° 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 h of midday summertime exposure. Apart from squinting, the photokeratitis threshold would be achieved in less than 15 min exposure for midday summer sunlight. When the sun is high in the sky, ocular exposure to sunlight reflected from snow (Table 6) produces snow blindness.

Influence of sun position on exposures in outdoor occupations

As described above, the strong dependence upon the position of the sun (latitude, elevation angle, and altitude) on the exposure received by the eyes and skin plays a major role in determining worker exposure and establishing the most appropriate control measure. 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. 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 delivery persons, and periods of training exercises for soldiers or sailors. Some fishermen may only have substantial outdoor tasks early 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. Some work shifts may not even cover the midday hours. 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.

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 (Sliney 1986).

Application of the ICNIRP exposure limit to solar exposure

The use of the ICNIRP exposure guideline in an outdoor setting poses many problems of adequate dose assessment both for the eye and the skin.

Solar ocular exposure, particularly in mid-summer, routinely appears to exceed the ICNIRP limit (ICNIRP 2004) even for relatively short exposure durations. The ICNIRP guideline limit for a daily exposure limit of 30 J m^{-2} (effective) is exceeded if measured on a horizontal surface in the summer under a clear sky condition or in tropical conditions within 6 min around solar noon. Of course this horizontal exposure would technically apply to the prone position with the eyes directed to the sun, which is unrealistic.

Under most situations, ocular exposure does not actually exceed the limit for even greater exposure duration extending to several hours (Sliney 1983, 1986, 1995). Indeed, the research work which developed the thresholds for photokeratoconjunctivitis 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 (Sliney 1983). This means that only in unusual, harsh environmental conditions where ground reflectance is high would one actually exceed the limit for exposure of the cornea. Certainly, snowblindness and photokeratoconjunctivitis are rarely experienced outdoors unless snow is on the ground and the sun elevation angle is sufficiently high.

For skin exposure, under the same conditions and using the CIE erythemal spectral effectiveness function, the time to achieve one SED (100 J m^{-2}) is approximately 5 min. At other times of the day, these durations will be longer. This clearly indicates that outdoor workers who belong to skin phototypes 1 to 4 would need to be well protected in such an environment. Estimating that ambient UVR is averaging 40 SED, the body sites uncovered by clothing receive ~10 SED per day on arms and legs for an 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, meaning that their skin has adapted to solar exposures. But accumulation of significant solar UVR may still have implication for the induction of skin cancer later in the life. Minimizing UVR exposure of outdoor workers clearly poses a challenge.

The ICNIRP (2004) and ACGIH (2009) guidelines recommend therefore that the UVR limits be considered as "ceiling values" for the eye, but desirable goals for the skin. In current practical hazard evaluation and risk assessment, it has become customary by many who apply the ACGIH TLV (threshold limit value) to recognize that it is a limit directly applicable to exposure of the cornea under worst-case conditions of normal incidence. However, 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.

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. Heavy-duty work clothes, such as denim coveralls, have UVR 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 (CIE 2006b). "Ultraviolet Protection Factor (UPF)" [also known as the "Clothing Protection Factor (CPF)" in some countries] is a unit used for a given fabric. This factor is defined as the ratio of the erythemally analogous to the Sun Protection Factor (SPF) quoted for sunscreens (CIE 2006b).

Although clothing is always preferable to protect the skin, broad-spectrum topical sunscreens with an SPF of at least 30 should be applied liberally on exposed skin areas when the UVR Index is 3 or greater for melano-compromised skin and 5 for melanoncompetent skin phototypes (Roy and Gies 1997). Sunscreen application is a secondary method of protection, and is 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 (Bech-Thomsen and Wulf 1993). 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, sweating, abrasion, or water immersion.

Eye and face protection is achieved best with broad brim hats that provide shade to the face and neck, preferably with neck flaps, and with eye protection with wrap-around design or sunglasses with side panels. "Wrap-around" glasses or goggles that fit close to the eyes provide better protection than more open designs. 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. Ocular exposures are greatest where UVR reflectance is high, as over snow or water, or even sand. UVR protective goggles are effective in reducing the ocular UVR exposure of the eyes from reflections from the snow.

During electric arc welding in the outdoor environment, added protection in the form of face shields and skin protection will be required.

Engineering controls—Shading structures

The presence of buildings, trees, mountains and other shading structures can significantly reduce the total UVR exposure of the skin and eyes. Certainly, when the direct view of the horizon sky is blocked, ocular exposure to UVR is greatly reduced. In outdoor occupations where the employee is in a relatively fixed position, such as a security sentry, shading structures can be employed to greatly reduce direct sun exposure. Other examples include canopies on earth-moving equipment, awnings on scaffolds and open tents at temporary outdoor meeting points. However, these are frequently less effective in blocking the diffuse sky radiation and ground reflection that determine ocular exposure. If the shade structure blocks only the direct sun exposure, one can actually experience sunburn from exposure to diffuse sky radiation. Glass in temporary buildings and glass enclosures on vehicles will spectrally block most UV-B, but may still transmit substantial levels of UV-A. Indeed, materials that are visibly clear will absorb UVR to varying degrees. For example, window glass transmits some radiation down to 310 nm, whereas most plastics such as polymethyl-methacralate, e.g., Perspex® or Lucite®, and polycarbonate normally do not transmit below about 370 nm. In general, windscreens on cars block both UV-A and UV-B (Sliney 1994b). Cockpit windscreens on airplanes block UV-B and UV-A (Diffey and Roscoe 1990).

Administrative control measures

Appropriate seasonal training is essential for all outdoor workers. In particular 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 mo period centered on the summer solstice, e.g., April to September in the northern hemisphere, when the UV Index (WHO et al. 2002) exceeds 3. Work practices should emphasize the value of avoiding exposure to direct sunlight during the period around noon in spring and summer and seeking shade during lunch breaks and where work practices permit. Workers should be informed of what are appropriate clothing and eyewear to provide an appropriate level of protection from UVR. Workers should be advised to avoid unnecessary additional elective UVR exposure, as from sun bed 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. Everyone should understand that although protection of the eye is essential for all races, skin protection is much more important for workers with sun-sensitive (melano-compromised) skin. The following guidance for training the latter category of workers in skin protection is therefore of importance.

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. A training program should provide an introductory talk on UVR awareness and protection advice appropriate to the job, and refresher briefings should be provided when appropriate, such as when moving to a new work site. Supervisory personnel may require additional training on the UVR risks to workers. Fact sheets on UVR exposure risks and safe practice along with training in the application of added control measures varying with increasing values of the UV Index (WHO et al. 2002) have been shown to be useful. Posting of the UV Index at work sites can maintain worker awareness. Workers must understand the UVR variability during the day and the impact of variable cloud conditions, and that 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. Thus, severe sunburn frequently occurs on an overcast summer day when the average person does not feel the warmth of the sun. But heavy, overcast skies do offer some protection. Supervisors and safety personnel should demonstrate (and provide) appropriate shirts and caps with neck-flaps, and also explain that loose-fitting, long-sleeve shirts and trousers are not necessarily "hot."

One simple rule-of-thumb that has been shown effective for many outdoor workers is the *shadow rule*. The shadow rule simply advises a person that if his or her shadow is shorter than their height, UVR protective precautions are particularly important. It recognizes the importance of atmospheric slant path. The UV Index (WHO et al. 2002) formulated by the World Meteorological Organization (WMO), World Health Organization (WHO), and ICNIRP to communicate a uniform message regarding the day's UVR exposure conditions indicates the general level of risk, whereas the shadow rule provides a simplified method to determine when the UV Index exceeds 4, provided that shadows exist. When the solar elevation angle and solar zenith angle both are 45° (shadow rule) and the UV Index is ~4, sensitive skin without adaptation will experience a noticeable sunburn from about two hours of exposure. Simple concepts that everyone can understand such as the "Slip, Slap, Slop, and Seek Shade" and "short shadow, seek shade" slogans are also of value.

Susceptibility

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.

The increase in UVR exposure from terrain reflections will be important for some occupations, such as those who work in and around water in open spaces or over ice and snow in early spring. Outdoor work during their 4 h 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.

INDOOR WORKERS—OCCUPATIONAL EXPOSURE TO ARTIFICIAL SOURCES

Artificial sources

Optical sources can be characterized by as arc discharge sources (e.g., welding arc, metal halide lamp), incandescent lamps (e.g., tungsten halogen lamp), semiconductor emitters [e.g., light-emitting diodes (LEDs)], and lasers (e.g., excimer laser). Artificial sources may provide additional exposure that may be elective, e.g., sunbathing, cosmetic tanning with sun beds, or medical therapy, or occur as a consequence of occupation, e.g., electric arc welders.

Artificial sources of UVR are used in many different applications in the working environment (Hietanen and Hoikkala 1990). In some cases, the UVR source is well contained within an enclosure and, under normal circumstances, presents no risk of exposure to personnel. However, accidental exposure may result from the failure of a protective enclosure. In other applications, it is inevitable that workers will be exposed under the normal work conditions, as in arc welding. In these cases, exposures will not only come directly, but also from reflections/scattering from adjacent surfaces.

Unlike sunlight, most artificial sources do not have a large change in spectrum or effective irradiance 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 influence the potential health risk: the source spectrum and biologically effective UVR emissions; the distance and position of the worker from the source; and the duration of the exposure of the worker, for the skin, and the skin type as well.

In contrast to the sun, an artificial UVR source is very frequently within the normal direct field-of-view of the worker, thus permitting direct exposure of the eye. Table 8 summarizes safety precautions for many types of artificial sources.

Table 8. Safety precautions against indoor UVR exposure health risks.[a]

Source	Potential for overexposure	Hazard description	Safety precautions
Open arcs (e.g, electric welding)	Very high	Welding arcs can exceed the UV radiation exposure limits 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 to reduce exposure.
Photocuring, photohardening and etching	Medium	UV lamps are usually inside cabinets, but UV radiation emitted through openings can potentially exceed the UV exposure limit in seconds.	Engineering controls to close openings. Training.
"Black lights" used in non destructive testing (NDT)	Medium to low	UVA lamps used in NDT in banking, commerce, materials inspection, and entertainment. "Black lights" used for insect control and entertainment are usually below exposure limits.	Engineering controls to reduce eye exposure (for instance by shields). If not possible or for higher power (arc) lamps used in NDT: PPE. No precautions needed for insect control and entertainment lamps, or lower power NDT 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 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.

[a] 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.

Typical sources of exposure in different applications

Arc welding represents a major source of worker exposure to potentially hazardous levels of UVR (Hietanen and von Nandelstadh 1998), whereas gas welding does not produce significant UVR levels. The arc current, shielding gas, and the metals being welded impact the emission, and specified eye protection varies accordingly. For example, arc welding of aluminum produces much more UVR than steel welding for the same current.

The germicidal application of short-wavelength UVC in the wavelength range of 250–265 nm represents another potential worker exposure to UVR. Low-pressure, mercury-discharge lamps are often the source of choice, since more than 90% of the radiated energy is in the 254 nm emission line. These lamps target viruses, bacteria, and molds, and are therefore generally referred to as germicidal lamps, bactericidal lamps, or simply UVC lamps (CIE 2003). Engineering controls such as enclosures and baffling normally prevent hazardous exposure. However, accidental exposure can occur from safety interlock failures, improper installation, or from inadequately trained servicing personnel, since exposure at short distances to bare lamps exceeds the exposure limit for the eye and the skin in only a few seconds.

Ultraviolet photo curing is employed in many industrial processes, such as the curing of lacquers, inks, glues, and sealants (UVR "drying"). UV-A sources are most typical. However, in special applications, sources may also emit UV-B and UV-C. High-power discharge lamps are generally housed in interlocked assemblies to protect personnel. Thus, hazardous exposures most frequently occur when interlocks malfunction or protective housing is removed.

UV-A "black-light" lamps are used for exciting fluorescence in many applications. Examples are checking banknotes by bank tellers and cashiers and

UV photography. In normal use, baffles protect the eyes from direct exposure and no occupational UVR hazard to the eye or the skin results. UV-A lamps are also found in discotheques, theatres, bars, and other entertainment facilities to induce visible fluorescence in clothing, posters, and other fluorescent materials. These UV-A exposures are normally well below exposure limits. UV-A lamps used in materials inspection and research laboratories to induce fluorescence are also normally used at low levels. In cases where exposure limits are exceeded, the hands can be protected by gloves, and the eye can usually be protected by shielding against a direct line of sight to the lamp.

Medical applications of UVR are typical in dermatological treatment facilities, and many phototherapy lamps emit high levels of UVR (Diffey 1989, 1999). 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. UVR sunlamps for cosmetic tanning are widespread and attendants can experience potentially hazardous occupational exposures. Hence, appropriate training to eliminate needless exposure is essential.

Fluorescent lamps used for general lighting in offices, homes, and factories emit small quantities of both UV-A and UV-B. UV-B emission depends upon the impurities in the glass envelope. However, photobiological safety standards for lamps and lighting equipment (CIE 2006a) require exempt lamps to be below 0.1 μW cm^{-2} (1 mW cm^{-2}) at a distance where the luminance equals 500 lux, and UVR blocking envelopes preclude hazardous emission of UVR from tungsten-halogen lamps. Recently, some compact fluorescent lamps were found to emit some of the 254 nm mercury line (i.e., UV-C) in the bends where the glass is thinned (Khazova and O'Hagan 2008). High intensity discharge (HID) mercury lamps and HID mercury fluorescent lamps are typically used for roadway lighting, high bay lighting and for lighting of construction sites. In these lamps, the outer envelope normally blocks the hazardous UVR. But, if that envelope is broken, the internal UVR discharge lamp may continue to operate and severe over-exposure of the eye and skin can occur. Workers who replace lamps in high bay areas such as sporting halls, air craft hangers and large industrial buildings must be trained to identify damaged lamps, and how to replace them safely. UV-A lamps are used in insect traps, but under normal use both occupational and public UVR exposure is very low and poses no hazard.

EXPOSURE ASSESSMENT AND MEASUREMENTS

The assessment of worker exposure is often performed from knowledge of the source and a work task analysis without the use of UVR measurement or monitoring instruments. However, the measurement or monitoring of UVR from artificial sources or from sunlight may be required for assessment of the worker's exposure in case of an accidental exposure or because of concerns about safety. A range of instruments of varying sophistication are available. The choice of a particular instrument will depend upon the accuracy and/or ease of use depending on the measurements that are required. The constantly changing position of the sun with time of day and season and changing meteorological conditions limits the usefulness of site-specific UVR measurements for predictive risk assessment in most outdoor occupations. However, an instrument may be used to demonstrate current exposure conditions to workers and the need for protection. National networks to measure the solar UVR may provide data for predictive purposes to the public on a daily basis, in the form of the UV Index. Knowledge of the UV Index and the shadow rule can help to choose the level of protective measures for outdoor workers.

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, UVR 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 2006a; IEC 2006) (Table 4). An "exempt" category of sources would require no further hazard assessment or protective measures, and protective measures for Risk Group 1 (Table 4) would only be necessary for prolonged exposures at short distances. A number of publications provide typical UVR emission characteristics of commercial UVR sources, including welding arcs (Sliney and Wolbarsht 1980; Harlen and Boyer 1985). 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 farther from the source. Measurements are most likely to be of value when assessing indoor exposures to UVR sources where the characteristics of the sources are generally fixed and work practices are repetitive.

Measurements of indoor workers exposure

Measurements or calculations to characterize the exposure level may be required to determine if the exposure limit is exceeded, so that protective measures such as shielding of the source or personal protection can 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 other workplace hazards, the UVR exposure level can vary drastically depending on the behavior of the worker or the process used. For example, for welding the UVR emission can strongly vary with the welding process and materials used. If measurements are needed to investigate an accident or because of an alleged relation to a disease, it is frequently not possible to reduce the measurement expenditure by choosing maximum values for unknown parameters. All exposure parameters need to be determined as precisely as possible. In addition to work site measurements, laboratory measurements may be made to determine the emission and spectrum of a radiation source. For example, the Risk Group of the lamp (Table 4) may be defined and reflective characteristics of some building materials may be estimated. Such information can be used to select necessary attenuation of a protective screen, barrier, or filter such as eye protection.

Measurement 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 uncertainty are not very demanding and rough estimates can suffice. However, if the exposure level is close to the exposure limit, a low uncertainty is needed. Since the uncertainty of a broad-band meter may strongly depend on the spectral distribution of the source, the actual uncertainty may be difficult to determine without a spectral measurement.

Personal dosimeters

Small, broad-band safety meters may be used as personal dosimeters, i.e., fixed to a person's clothing or hat and worn during the workday. Personal electro-optic dosimeters either add up the dose continuously or record the time varying irradiance to be read out after the working day. In addition to these electro-optic dosimeters, a number of film dosimeters have been developed that are based on photoinduced changes of chemical or biological materials. The magnitude of the change is related to the effective UVR dose. The film dosimeters thus accumulate the exposure over a designated time and are subsequently analyzed in a laboratory. Due to the delay between exposure and measurement result, the film dosimeters are only relevant for scientific studies of exposure levels, not for warning of the wearer when over-exposure is occurring.

Practical procedure for avoiding indoor over-exposure

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 be careful not to judge the source of UVR 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 UVR spectral region, particularly in the UV-B and UV-C regions. Some metals, particularly aluminum, maybe highly reflective in the UVR wavelength range. For instance, reflections might become relevant if protective measures, such as face shields, do not protect against radiation from all directions.

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 (Fig. 7) and if appropriate the need for personal protection.

Warning lights may also be used to show when the equipment is energized

Welders should be protected by a welding helmet or mask fitted with absorption filters, which meet appropriate standards, as illustrated in Fig. 8.

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 should be used for protection.

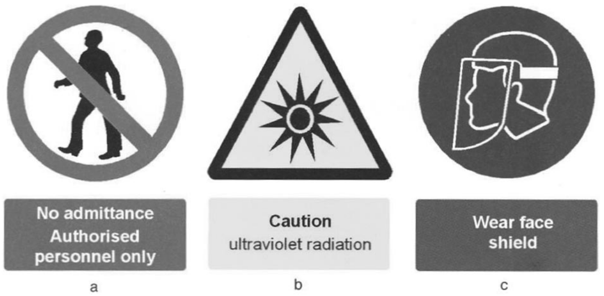

Fig. 7. Typical signs used in the work environment to advise of hazards and recommend the use of personal protective equipment.

Fig. 8. Welder with appropriate personal protective equipment (NRPB 2002).

HEALTH SURVEILLANCE

It is important that, where occupational health programs for outdoor workers exist, they address the adverse effects of solar UVR exposure. If medical surveillance is performed, both eye and skin exams would be appropriate:

- Skin examinations should focus on moles, keratoses, and abnormal pigmentation; and
- Ocular examination should focus on eyelid tumors, pinguecula, pterygium, corneal opacities, cataract, and history of photokeratoconjuctivitis.

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 UVR is an occupational hazard for all outdoor workers;
- Outdoor workers can receive many times the UVR dose of indoor workers;
- The relevant national authority has to be convinced of the health risks of excessive levels of UVR in order to take action;
- Employers have to be convinced of their responsibility; and
- There is a need to identify requirements for the program based upon a health risk assessment of the exposed worker population, considering: (a) Evaluation of seasonal variation of the effective environmental UVR exposure; (b) Solar ultraviolet radiation exposure; Global UV Index (WHO et al. 2002); (c) Evaluation of effective UVR exposure on unprotected skin and eyes; and (d) Potential for shielding with outdoor clothing and special work clothing.

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:

- Provision of information, simple posters with cartoons, the use of slogans, and simple explanations of the UV Index and the shadow rule;
- Demonstration and distribution of appropriate shirts and caps with neck-flaps;
- Promotion of loose-fitting, long-sleeve shirts; and
- Promotion of sunscreen use. Sunscreen cream dispensers should be installed at the work site.

Program assessment

In some past UVR educational campaigns, reviews have taken place after each summer by evaluation forms and periodic interviews. e.g., the quantity of sunscreens used and pictures taken during working hours for evaluation of proportion of workers that wear hats and appropriate clothes have been analyzed. Interviews with randomly selected workers have focused on the link between precautions and their goal: "Good for the skin" or reduction of 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; and
- Personal protection by hats, clothes, sunscreens, and 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, and plasticized information cards. 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); and
- Apply sunscreen with a protection factor of SPF 15–30 every 2 h.

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 UVR radiation. However, the role of ambient temperature with UVR 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.

CONCLUSION

The boundaries between the risks and the benefits of UVR radiation are not clearly defined. The health risks associated with excessive UVR exposure to the eye and skin are well characterized and known. For artificial UVR sources at the workplace, i.e., exposure of the "indoor" worker, exposure of the skin and eye to levels above the ICNIRP exposure limits can usually be prevented by engineering controls (shielding) or by personal protective equipment. It is not clear whether there are benefits from UVR exposure at levels above the ICNIRP exposure limits (ICNIRP 2004). It is recognized that the risks of UVR exposure of the skin differ greatly depending on skin phototypes. For the dark skin population, the position and quality of melanin in the stratum corneum provide a very import shield against UV-B (Clemens et al. 1982). Therefore, skin protection must be emphasized for skin phototypes I–IV (Table 2). 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 ocular exposure dose (Sliney 1995).

Severe sunburns and cumulative UVR exposures are two factors which have been recognized as responsible for skin cancers. ICNIRP and WHO strongly recommend reducing UVR exposure in order to reduce the burden of skin cancer (WHO et al. 2002). The UVR health risk strongly depends on skin phototype. Therefore, risk communications should be improved aiming to be suitable for all, but particularly focusing on the melano-compromised workers, and should be seasonally appropriate.

A broad-brimmed hat should be worn when the UV Index is above 3. Improvements of sun protective fabrics that can be employed in loose-fitting work clothes designs are needed. This is particularly important where protection against heat stress is required. The actual use of sunscreens by workers as a protective measure has been shown to be unreliable, despite their effectiveness in reducing erythema. Protection by sunscreens should be a protective measure only when other measures are not practical. Protective eyewear against UVR is counter protective if radiant energy from around the frame reaches the eye, as from the side.

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