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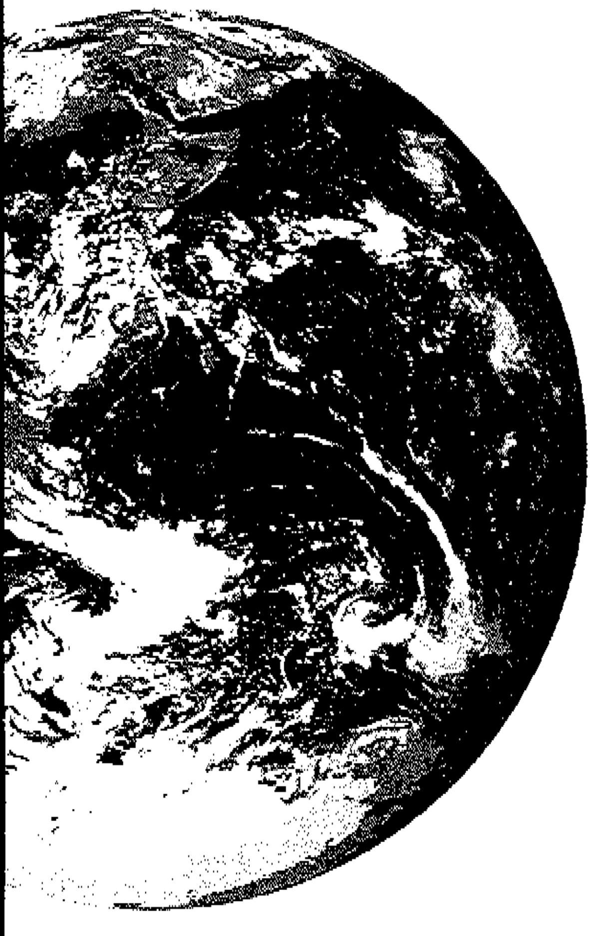

HEALTH AND ENVIRONMENTAL EFFECTS OF ULTRAVIOLET RADIATION

A summary of Environmental Health Criteria 160 Ultraviolet Radiation

GENEVA, 1995

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Introduction

A monograph entitled Environmental Health Criteria 160 «Ultraviolet Radiation» was published in 1994 by the World Health Organization, the United Nations Environment Programme (UNEP) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The monograph was the result of an in-depth review of the scientific literature and was primarily concerned with the effects of ultraviolet (UV) radiation exposure on human health and the environment. The penultimate draft was subjected to a WHO Task Group for final peer review prior to publication. Such a publication was considered particularly timely in view of the consequences of increasing levels of UV at the surface of the earth resulting from depletion of stratospheric ozone.

The purpose of this document is to provide a summarised form of the monograph, allowing a more general readership to have access to the information, and to provide an update on activities that have resulted from the recommendations of the Task Group that reviewed the monograph.

Exposure to UV occurs from both natural and artificial sources. The sun is the principal source of exposure for most people. Solar UV undergoes significant absorption by the atmosphere. With depletion of the stratospheric ozone people and the environment will be exposed to higher intensities of UV. The consequences of this added UV exposure are considered so serious that it was a major topic for discussion at the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992. Agenda 21, adopted by the Conference, specifically recommends to «undertake, as a matter of urgency, research on the effects on human health of the increasing ultraviolet radiation reaching the earth's surface as the consequence of depletion of the stratospheric ozone layer.» It is this issue that underscores the current need to better understand the potential health and environmental risks of UV exposure and the changes in life-style needed to reduce UV exposure.

The scientific evidence shows that ozone depletion is caused by human-made chemicals and will persist till chlorine and bromine levels are reduced. The world community has in response to this evidence agreed, under the auspices of UNEP, on the Vienna Convention for the protection of the Ozone Layer in 1985 and on the Montreal Protocol on substances that deplete the ozone layer in 1987 (and amended in 1990 and 1992). The thrust of these agreements is to phase out the ozone depleting substances. 150 nations have ratified these agreements. A consumption of a million tonnes (in 1986) of the developed countries will be almost completely phased out by 1996 and the developing countries will phase out their consumption of about 200,000 tonnes before the year 2010. However, the long life of the chemicals already released will cause further ozone depletion for the next few years and the ozone layer is expected to fully recover in about 50 years.

INTERSUN, a global UV project, is UNEP and WHO's response to the need to disseminate information about the health and environmental hazards of excessive UV exposure. INTERSUN has developed a document entitled «UV Protective Measures» in response to the need to educate the public and particularly workers exposed to UV, on measures they can take to reduce their UV exposure. It has been involved in the development of a Solar UV Index, an index related to daily UV exposure, reported with the news and weather, that facilitates a continuing educational process about possible health effects and measures to reduce UV exposure. More details on these programmes are given at the end of this text.

Summary of the major health concerns

Skin cancer and cataracts are important public health concerns. The social cost of these diseases, such as death, disfigurement, blindness, and weakening the immune system can be overwhelming both in terms of human suffering and the financial burden. Solar UV exposure is known to be associated with various skin cancers, accelerated skin ageing, cataract of the lens of the eye and other eye diseases, and possibly has an adverse effect a person's ability to resist infectious diseases. Most of these health concerns could be avoided by reducing exposure to solar UV.

UNEP estimates that over two million non-melanoma skin cancers and 200,000 malignant melanomas occur globally each year. In the event of a 10% decrease in stratospheric ozone, with current trends and behaviour, an additional 300,000 non-melanoma and 4,500 melanoma skin cancers could be expected world-wide.

Some 12 to 15 million people in the world are blind because they have cataracts. According to WHO, up to 20% of cataracts, that is three million per year could be due to UV exposure to the eye. Expert believe that for each 1% sustained decrease in stratospheric ozone there would be an increase of 0.5% in the number of cataracts caused by solar UV (van der Leun et al 1989). In the United States alone, it costs the US Government $US 3.4 billion for 1.2 million cataract operations per year. Substantial savings in cost to health care can be made by prevention or delay in the onset of cataracts.

Ultraviolet radiation

UV is one of the non-ionizing radiations in the electromagnetic spectrum and lies within the range of wavelengths 100 nm to 400 nm. The short wavelength limit of the UV region is often taken as the boundary between the ionizing radiation spectrum (wavelengths < 100 nm) and the non-ionizing radiation spectrum. UV can be classified into UVA (315 -400 nm), UVB (280 -315 nm) and UVC (100 - 280 nm) regions, although other conventions for UVA, UVB and UVC wavelength bands are in use.

The sun is the strongest source of UV in our environment. As sunlight passes through the atmosphere, all the UVC is absorbed and all except a small percentage of the UVB is absorbed by atmospheric components such as ozone, water vapour, oxygen and carbon dioxide. Figure 1 shows how the optical emissions of the sun are absorbed by various components of the earth's atmosphere. Snow is a particularly strong reflector of UV (almost 80% of the incident UV is reflected).

Most artificial sources of UV, except for lasers, emit a spectral continuum of UV containing characteristic peaks, troughs and lines. These sources include various lamps used in medicine, industry, commerce, research and the home.

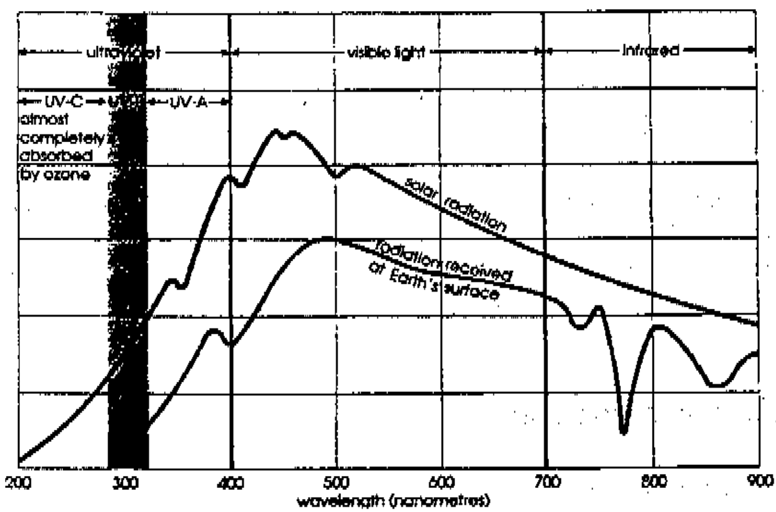

Figure 1: Solar optical emissions before and after absorption by the atmosphere

Since UV is normally absorbed over a surface it can be measured as a radiant exposure, the incident UV energy divided by the receptor surface area in joules per square metre ($J\ m^{-2}$). UV can also be measured as an irradiance, the incident power divided by the receptor surface area in watts per square metre ($W\ m^{-2}$).

Biological effectiveness of UV

UV-induced biological effects depend on the wavelengths of the radiation emitted by the source. Thus, for a proper determination of hazard it is necessary to have information on the spectral (range of wavelength) emissions. These consist of spectral irradiance ($W\ m^{-2}\ nm^{-1}$) measurements from the source. The total irradiance ($W\ m^{-2}$) is obtained by summing up all the wavelengths emitted. The effective UV irradiance ($W\ m^{-2}$ effective) or dose rate is determined by multiplying the spectral irradiance at each wavelength by the biological or hazard weighting factor (which quantifies the relative efficacy at each wavelength for causing the effect) and summing over all wavelengths. Such factors or weighting functions are obtained from action spectra.

Action spectrum and minimum erythemal dose

An action spectrum is a graph that provides information on the effectiveness of the UV wavelengths in producing a biological effect, eg erythema (reddening of the skin). It is the reciprocal of the radiant exposure required to produce the given effect at each wavelength. Figure 2 depicts the ICNIRP-CIE action spectrum for erythema. All the data in such curves are normalized to the most effective wavelength(s). By summing the biologically effective irradiance over the exposure period, the biologically effective radiant exposure ($J\ m^{-2}$ effective) can be calculated.

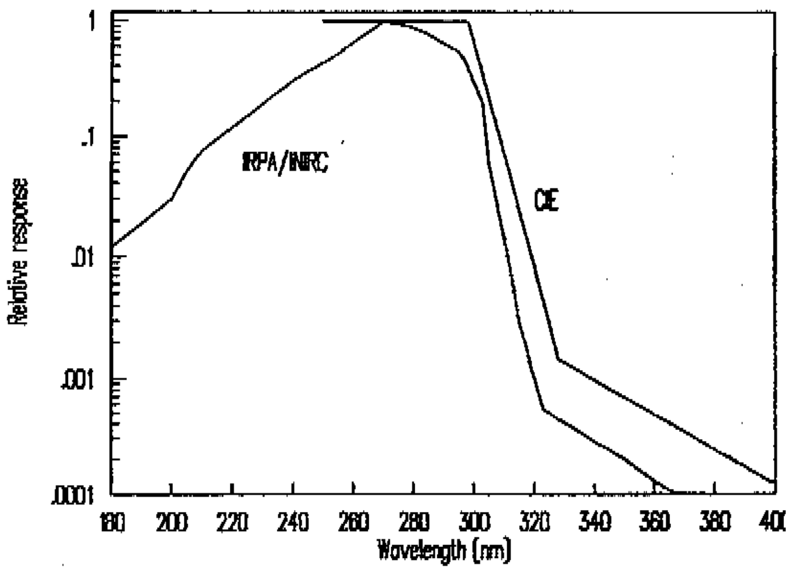

Figure 2: Action spectrum for erythema

For UV induced erythema, the action spectrum adopted by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), International Commission on Illumination (CIE), the International Electrotechnical Commission (IEC) and various national bodies, is a composite curve obtained by statistical analysis of many research results on the minimum radiant exposure of UV at different wavelengths necessary to cause erythema.

The most commonly used quantity for describing the erythemal potential of an exposure to UV is the number of minimum erythemal doses (MEDs) represented by the exposure. A MED is the radiant exposure of UV that produces a barely noticeable reddening on a previously unexposed skin. It corresponds to a radiant exposure of monochromatic radiation at the maximum spectral efficacy for erythema (around 300 nm) of approximately 150 to 2000 J m^{-2} effective, depending on skin type. Values of 200 - 300 J m^{-2} effective are commonly used as the value of 1 MED for comparative safety purposes for white skin.

Cellular and molecular studies

To produce any change, UV must be absorbed by a biological molecule. This involves absorption of a single photon by the molecule and the production of an excited state in which one electron of the absorbing molecule is raised to a higher energy level. The primary products caused by UV exposure are generally reactive species or free radicals which form extremely quickly but which can produce effects that can last for hours, days or even years. DNA is the most critical target for damage by UVB and UVC, but the question as to which lesion constitutes the most important type of pre-mutagenic damage remains controversial.

Animal studies

Skin cancer

Solar UV exposure has been shown to produce cancers in animals. UV causes predominantly squamous cell carcinomas (SCCs). UVB is most effective at producing SCCs, although they are produced by UVA but at much higher doses (irradiance x exposure time). The effectiveness of UVC is unknown except at one wavelength (254 nm). At this wavelength the effectiveness is less than that of UVB.

Melanomas are much less common and only two animal models have been found for induction of melanoma by UV alone. An initial action spectrum determined for a type of hybrid fish indicates a peak in the UVB range but also shows a high level of effectiveness in the UVA. Basal cell carcinomas are rare in animals.

Immune response

Exposure to suberythemal doses of UV have been shown to exacerbate a variety of infections in rodent models. UV has an impact on infections both at the site of exposure and at distant sites. Recent work indicates that systemic infections without skin involvement may be affected. Enhanced susceptibility appears to result from T-helper cell activity. The mechanisms associated with this suppression appear to be the same as those identified with suppression to contact and delayed type hypersensitivity responses. Suppression of these immune responses appears to be mediated by the release of soluble mediators from UVB exposed skin which alters the antigen presentation by Langerhans and other cells so that they fail to activate TH1 cells. The resulting immune suppression is antigen specific, and can occur regardless of whether or not antigen is applied at the site of exposure. It is relatively long lasting. UV exposure also reduces the effectiveness of vaccinations for a variety of infections in mice and rats.

Effects on the eye

In many animals, including horses, sheep, swine, cats and dogs, cancers of the eye occur and are particularly frequent in cattle (Ozone Depletion Panel Report 1994). UVB exposure has induced ocular tumours in mice, rats, hamsters and opossums.

Many studies in experimental animals have demonstrated that UV exposure (mainly UVB) can cause both acute and delayed effects such as cataract, photokeratitis, damage to the corneal epithelium and various retinal effects.

Studies of injury in aphakic monkeys have shown that the retina is six times more vulnerable to photochemical damage from UV than the visible wavelengths. Bovine eye infectious keratoconjunctivitis is triggered and aggravated by UVB exposure of the eye.

Health effects on humans

Skin

The degree of damage that UV produces in skin will depend on the incident intensity and wavelength content (UVA or UVB), and on the depth of penetration of these wavelengths into the skin (see figure 3). Acute effects on the skin consist of solar erythema, «sunburn», which, if severe enough, may result in blistering and destruction of the surface of the skin with secondary infection and systemic effects, similar to those resulting from a first or second degree heat burn. Although UVC is very efficiently absorbed by nucleic acids, the overlying dead layers of skin absorb the radiation to such a degree that there is only mild erythema and, usually, no late sequelae, even after repeated exposures. UVA in high doses can cause erythema and tanning; however, doses of UVA, which alone may not show any biological effect, can, in the presence of certain environmental, consumer and medicinal chemical agents, result in injury to tissues (phototoxicity, photoallergy).

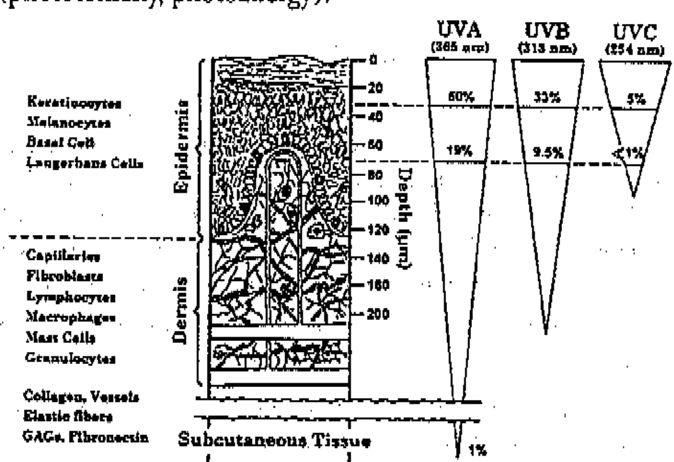

Figure 3: Depth of penetration of UV into the skin

Chronic skin changes due to UV consist of skin cancer (both melanoma and non-melanocytic), benign abnormalities of melanocytes (freckles, melanocytic naevi and solar or senile lentigines), and a range of other chronic injuries resulting from UV exposure to keratinocytes, blood vessels and fibrous tissue, often described as «photoaging» (solar elastosis). The much increased rates of skin cancer in patients with xeroderma pigmentosum, who have a deficiency in the capacity to repair UV-induced DNA damage, suggest that direct UV damage of the DNA may be a step in the cause of these cancers. This suggestion has also been supported by the observation of UV specific mutations of the p53 tumour suppressor gene in a proportion of patients with non-melanocytic skin cancer. Oxidative and immune suppressant effects may also contribute to the capacity of UV to cause skin cancers.

The worldwide incidence of malignant melanoma has continued to increase. Cutaneous melanoma is the result of neoplastic transformation of melanocytes, the pigment producing cells in the epidermis. Four basic categories of melanoma have been identified in humans: superficial spreading melanoma, nodular melanoma, lentigo malignant melanoma (also known as Hutchinson's melanotic freckle), and unclassified melanoma.

Melanoma is strongly related to frequency of recreational exposure to the sun and to history of sunburns. The evidence that risk of melanoma is related to intermittent exposure to UV, especially in childhood, is inferred from the locations of the melanomas over the body (larger numbers on irregularly exposed sites), higher occurrence in indoor than in outdoor workers, and higher levels of exposure during childhood (prior to 15-20 years of age).

There is suggestive evidence that exposure to sunlamps may increase the risk of melanoma, but the studies conducted so far have not consistently controlled for other factors that could influence the results.

Immune system

Skin is an important immunological organ, the immune system is vulnerable to modification by environmental agents such as UV. UV appears to alter immune response by changing the activity and distribution of the cells responsible for triggering these responses.

A number of studies indicate that UV exposures at environmental levels suppress immune responses in both rodents and man. In rodents this immune suppression results in enhanced susceptibility to certain infectious diseases with skin involvement and some systemic infections. Mechanisms associated with UV-induced immunosuppression and host defence mechanisms which provide for protection against infectious agents, are similar in rodents and man. It is therefore reasonable to assume that exposure to UV may enhance the risk of infection and decrease the effectiveness of vaccines in humans. Additional research is necessary to substantiate this.

Eye

UV exposure of the eye depends on many factors: ground reflection, degree of brightness in the sky leading to activation of the squint reflex, the amount of atmospheric reflection and the use of eye ware. In addition, the target for UV-induced damage will depend on the wavelength of the incident radiation as shown in figure 4.

The acute effects of UV on the eyes consist of the development of photokeratitis and photoconjunctivitis, which are painful but usually reversible and easily prevented by protective eye wear. Chronic effects on the eye consist of the development of pterygium and squamous cell cancer of the conjunctiva and cataracts. A review of the studies suggests that there is sufficient evidence to link acute ocular exposure to photokeratitis but our knowledge of the effects of chronic exposure is less certain. While there is sufficient evidence that cortical and posterior subcapsular cataracts (PSC) can be caused by UVB in laboratory animals, there is limited evidence to link cortical and PSC cataracts in humans to chronic ocular exposure to UVB.

Insufficient information is available to separate out the other factors contributing to cataract formation, or to state the proportion of cataracts which can be attributed to UVB exposure. There is also limited evidence to link the development of climatic droplet keratopathy and pterygium, but insufficient evidence to link uveal melanoma with UV exposure.

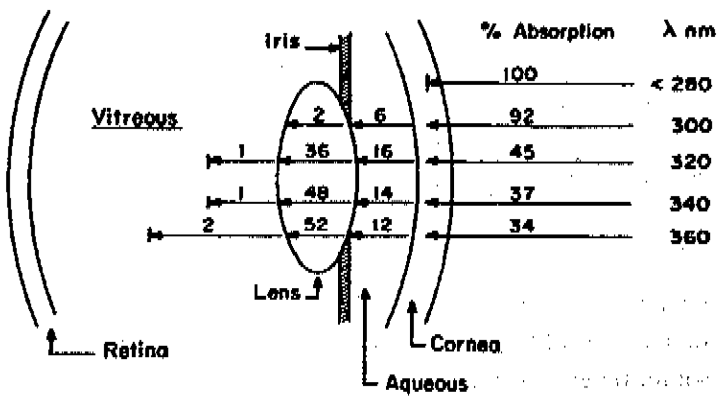

Figure 4: Depth of penetration of UV into the eye Environment

Environment

Increased levels of UV due to ozone layer depletion may have serious consequences for living organisms. A 10% reduction in ozone could lead to as much as a 15-20% increase in effective UV exposure depending on the biological process being considered. While the impact on human health, crop production, fisheries etc. is largely unknown, adverse effects of increased exposure to UVB have been reported on plant growth, photosynthesis and disease resistance. Furthermore, the impact of increased UV levels on aquatic ecosystems (the major contributor to the earth's biomass) may be substantial (see figure 5).

Phytoplankton, at the base of the aquatic food chain, serves as food for larvae of fish and shrimp. These in turn are consumed by fish, which subsequently provide an essential food source for many human beings and other animals. A significant reduction in phytoplankton from increased UVB exposure will directly affect the human and animal marine food source.

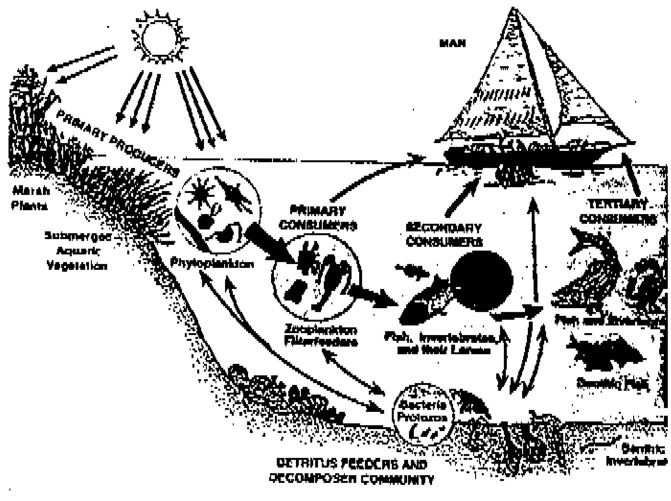

Figure 5: Biological food web in a marine ecosystem

Guidelines on exposure limits

International guidelines published by the International Commission on Non-Ionizing Radiation Protection define exposure limits (ELs) below which it is expected that nearly all people may be repeatedly exposed without adverse effects. The ELs are intended to be used to evaluate potentially hazardous exposures from, for example, solar radiation, arcs, gas and vapour discharges, fluorescent lamps and incandescent sources. The ELs are generally below levels which are often used for the UV exposure of patients required as part of medical treatment and below levels associated with sunbed exposure. ELs are not intended to apply to exposure of pathologically photosensitive individuals, to people concomitantly exposed to photosensitizing agents or to neonates.

Protective measures

Typical protection and control measures to reduce UV exposure include the containment of UV sources, and methods for personal protection including the use of sunscreen preparations, clothing, eye and skin protection, and changes in our behaviour when in the sun. People should enjoy the sun but be aware of the dangers to health of excessive UV exposure, and take the simple precautions to reduce UV exposure to the levels necessary.

With increasing levels of solar UV resulting from depletion of the ozone layer, and the continuing rise in the level of melanoma worldwide, people should become more aware of their UV exposure and take appropriate precautions. These precautions include staying out of the sun during the period around noon (the period when the UV levels are highest). Use of wide brimmed hats, protective clothing and UV absorbing eye glasses is still the best personal protection against the adverse effects of UV exposure.

Protection of young children is particularly important for the prevention of long-term consequences of UV exposure. In general life-style and behavioural patterns must change to protect against increasing solar UV levels.

Broad spectrum (UVB and UVA protective) sunscreens should be used when other means of protection are not feasible. These sunscreens should be used to reduce exposure rather than lengthen the period of exposure to the sun. While topical application of sunscreen is a preferred method of absorbing UVB, some preparations do not absorb the longer wavelength UVA effectively. Moreover, some have been found to contain ingredients that are mutagenic in sunlight. There is still much research to be conducted before the impact on health of increased levels of UVA is known. In the meantime, people using sunscreens should use those with a high sun protection factor (SPF) and be aware that they are for their protection from the sun and not for tanning purposes.

The reflective properties of the ground have an influence on UV exposure. Most natural surfaces such as grass, soil and water reflect less than 10% of incident UV. However, fresh snow strongly reflects (80%) UV. During Spring in higher altitudes, under clear skies, reflection from snow could increase UV exposure levels to those encountered during Summer. Sand also reflects (10-25%) and can significantly increase UV exposure at the beach. Thus UV protective measures must take account of the exposure conditions. UV exposure from various part of our living environment is shown in figure 6

Education

UV Protective Measures Publication

This INTERSUN publication provides information to people on how to protect themselves from the potentially harmful effects of exposure to ultraviolet radiation (UV). Following a detailed review of the scientific literature conducted by a WHO Task Group, a number of adverse health effects resulting from exposure to UV have been identified that need to be addressed through further research and more particularly through educational programmes for people most exposed to UV.

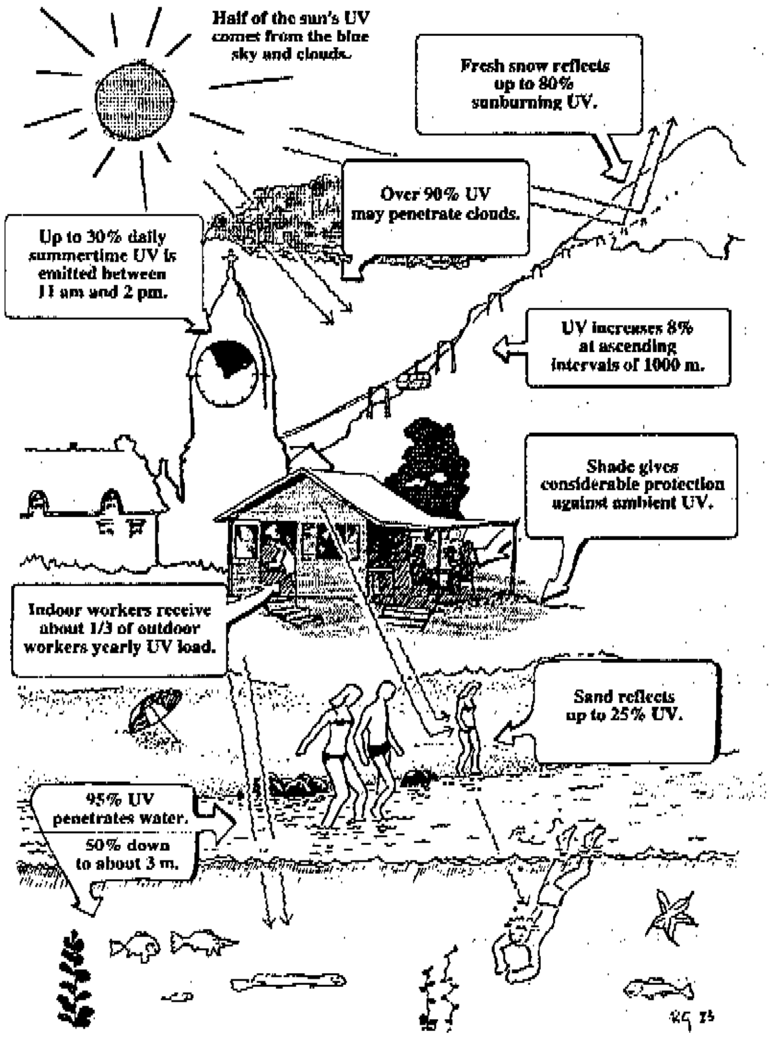

Figure 6: UV exposure from various parts of our living environment (Modified from Diffey BL and Larkö O, Clinical climatology. Photodermatology 1984, 1:30-37. With permission.)

The purpose of this document is to provide information to the general public and especially workers exposed to UV, on the various health hazards known to be associated with excessive exposure to UV and measures that can be taken to reduce this exposure to acceptable levels.

Solar UV Index

A joint initiative of the World Meteorological Organization, International Commission Non-Ionizing Radiation Protection, UNEP and WHO has resulted in the publication of a report that outlines the details of an internationally acceptable solar UV index, the use of which will be encouraged in the radio and TV news and weather programmes, and in the print media worldwide. The solar UV index is related to the UV exposure a person would receive outdoors. It identifies periods of the day when UV exposure may be intense and provides a tool to educate the public and outdoor workers about the hazards of excessive UV exposure and what precautions may be necessary to avoid such exposure. The initiative for this project was taken by the International Commission Non-Ionizing Radiation Protection and WHO Collaborating Centre in the German Government's Institute for Radiation Hygiene.

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