SOLAR RADIATION: AN UNDERESTIMATED OCCUPATIONAL RISK

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Cancun

18-23 March 2012

HEALTH IMPACT OF SOLAR RADIATION

The Sun had a major role in the development of life on Earth: Solar radiation has played the main role in the primordial synthesis of biomolecules and evolution of life; Ultraviolet (UV) radiation-induced mutations have expedited the process.

HEALTH IMPACT OF SOLAR RADIATION

Sunlight is fundamental for life:
it carries the energy for photosynthesis
is necessary for vitamin D synthesis, etc.

HEALTH IMPACT OF SOLAR RADIATION

An increasing body of data suggest that adequate UV exposure may reduce the risk of various relevant diseases:

- some types of cancer, as colorectal adenoma (Norval, 2011), possibly breast cancer (IARC 2008) and other
- multiple sclerosis (Asherio, 2007; Sloka 2008; Taylor, 2010; Westerberg, 2009), possibly rheumatoid arthritis
- Type 1 diabetes mellitus (Atkinson, 2001; Norval 2011)
- some infectious diseases, as TB (Yesudian, 2008)
- cardiovascular diseases (Krause, 1998; Giovannucci, 2008)
- some psychiatric disorders (WHO, 2006)

Evidence of causality not yet considered adequate (WHO, 2006)

THE PROBLEM:

Sunlight was, and is, fundamental for life on the hearth

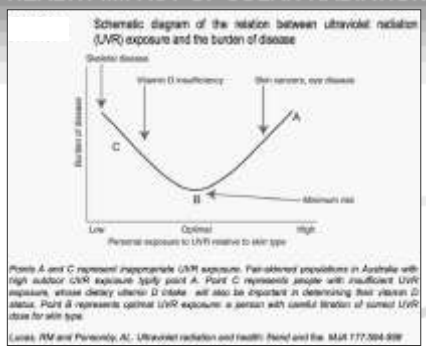
THE PROBLEM:

Solar radiation was, and is, fundamental for life on the hearth

BUT

(part of) sunlight radiation has also relevant detrimental health effects: globally, in the year 2000, excessive solar UVR exposure caused the loss of approximately 1.5 million DALYs (Disability-Adjusted Life Years) and 60 000 premature deaths. The greatest burden results from UVR-induced cortical cataracts, cutaneous malignant melanoma and sunburn (WHO 2006)"

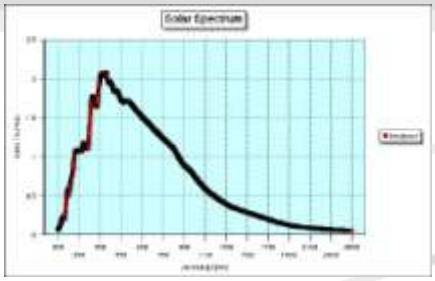
HEALTH IMPACT OF SOLAR RADIATION



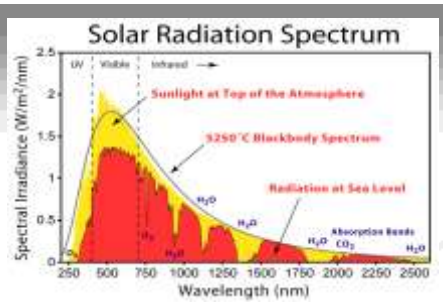
Points A and C represent inappropriate UVR exposure. Fair-skinned populations in Australia with high outdoor UVR exposure typify point A. Point C represents people with insufficient UVR exposure, whose dietary vitamin D intake will also be important in determining their vitamin D status. Point B represents optimal UVR exposure: a person with careful titration of sunract UVR dose for skin type.

Lucas, RM and Ponsonby, AL. Ultraviolet radiation and health: friend and foe. MJA 177:504-509

The spectral distribution of the solar radiation reching the Earth's surface depends on the irradiance emitted by the sun.



From European Space Agency (ESA)



This figure shows the solar radiation spectrum for direct light at both the top of the Earth's atmosphere and at sea level. The sun produces light with a distribution similar to what would be expected from a 5525 K (5250 ° C) blackbody, which is approximately the sun's surface temperature. As light passes through the atmosphere, some is absorbed by gases with specific absorption bands. Additional light is redistributed by Raleigh scattering, which is responsible for the atmosphere's blue color

SOLAR RADIATION

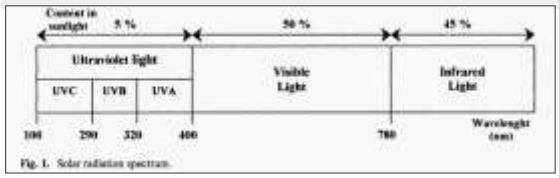


Fig. 1. Solar radiation spectrum.

From Svobodova et al, 2006

Frequencies of sunlight spectrum: Relevance for health risk (arbitrary proportions)

UV 5%

VISIBLE 50%

INFRARED 45%

UV CLASSIFICATION

- ***UVA*** *400-315nm*
- ***UVB*** *315-280nm*
- ***UVC*** *280-100nm* *(Second Internat. Congr on Light, 1932)*

The subdivisions are arbitrary. Environmental and dermatological photobiologists sometimes use slightly different divisions, more closely associated with the biological effect of the different wavelengths (WHO, 2006):

- ***UVA*** *400-320nm (UVA-1: >340-400, and UVA-2: 320-340)*
- ***UVB*** *320-290nm*
- ***UVC*** *290-200nm*

UV RADIATION

- ***UVA**: comprises about 95 % (94 - 97%) of solar UV radiation at ground level (Diffey, 2002; Roy et al, 1998).*
- ***UVB**: normally only 5% (3 - 6 %) of UVB reach the ground; the reduction of ozone layer increase UVB band*
- ***UVC**: completely absorbed by the ozon layer*

UV RADIATION

MAIN FACTORS INFLUENCING UV RADIATION:

- *Stratospheric ozone levels*
- *Latitude*
- *Altitude above the sea level*
- *Season / hour of the day*
- *Cloud cover*
- *Atmospheric pollution*
- *Ground reflection*
- *Other*

UV RADIATION

MAIN FACTORS INFLUENCING UV RADIATION:

Stratospheric ozone levels

- *industrialization produces chemicals (chlorofluorocarbons –CFCs-) reacting with the stratospheric ozone*
- *the loss of stratospheric ozone associated with increasing levels of ultraviolet radiation reaching the Earth´s surface*
- *difficult to assess changes in UVR due to stratospheric ozone depletion using ground-based measurements, (e.g. UVR changes with fluctuations in cloud cover), and increase in lower atmospheric pollution*
- *monitoring in the Swiss Alps, where the atmosphere is relatively clear has indicated slightly increased levels of UVR in the northern hemisphere, and in Australia has demonstrated increased levels of ambient UVR in months when cloud cover has been particularly low (Selgrade et al, 1997).*

UV RADIATION

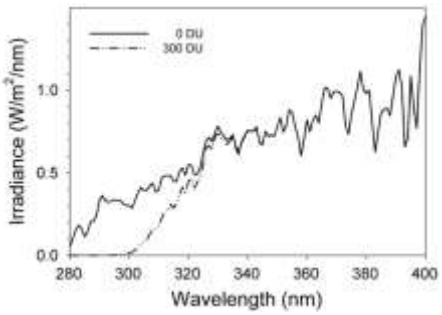
MAIN FACTORS INFLUENCING UV RADIATION:

Stratospheric ozone levels

From: http://www.epa.gov/air/emissions/

EFFECT OF OZONE LAYER ON SPECTRAL SURFACE UV IRRADIANCE.

Calculations for an atmosphere with normal ozone conditions and in the totally unrealistic case of no ozone



Juzeniene et al, Rep Progr Phys 2011

UV RADIATION

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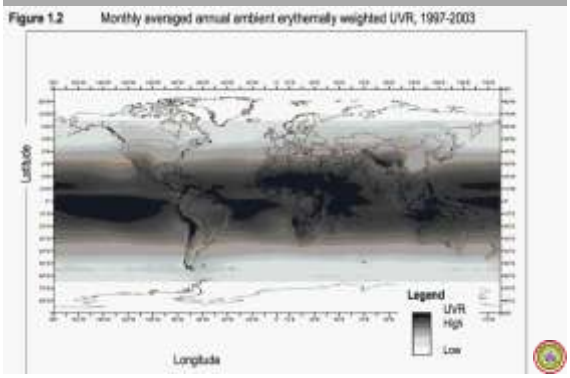
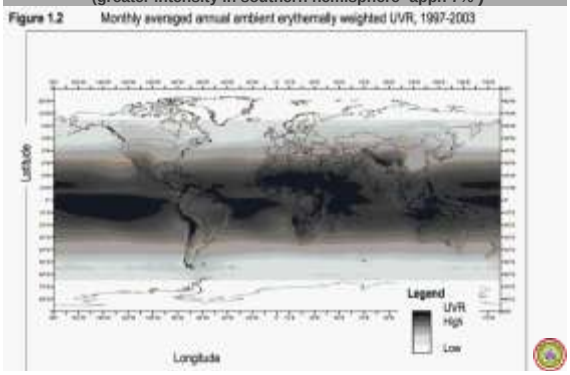
MAIN FACTORS INFLUENCING UV RADIATION: Latitude



MAIN FACTORS INFLUENCING UV RADIATION: Latitude
(greater intensity in southern hemisphere -appr. 7%-)



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- *Ground reflection*
- *Other*

MAIN FACTORS INFLUENCING UV RADIATION:
Season / hour of the day

- *The ultraviolet radiation component in the solar spectrum varies greatly with season.*
- *In the summer, UV-B radiation at midday can produce erythema in sensitive skin in less than 20 min in middle latitudes, while in winter months, the same midday exposure dose would require hours of exposure (Sliney, 2006).*
- *The large part of exposure in outdoor activities is during the central hours of the day: an observational study in Denmark showed that 50% of total UV dose reaches the earth between 1200 and 1500h (Thieden et al, 2004)*

UV RADIATION

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- *Ground reflection*
- *Other*

GROUND REFLECTION

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).

From: ICNIRP, 2010

MAIN FACTORS INFLUENCING UV RADIATION:
Individual Factors

- *Population groups are not homogeneous as regards to UV exposure*
- *In some subjects, 1 to 2 order of magnitude difference in individual exposure compared to the mean (Gies et al, 1999)*
- *It would be erroneous to apply precise estimate of ground level UVR as accurate estimates of personal exposure*

UV RADIATION

MAIN FACTORS INFLUENCING HEALTH IMPACT OF UV

Genetic
- Skin pigmentation
- Sun sensitivity
- Disorders

Cultural
- Dress
- Behaviours (sun-seeking / sun-protective)

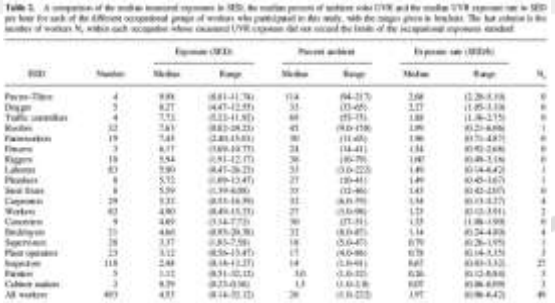
Occupational

OUTDOOR WORKERS

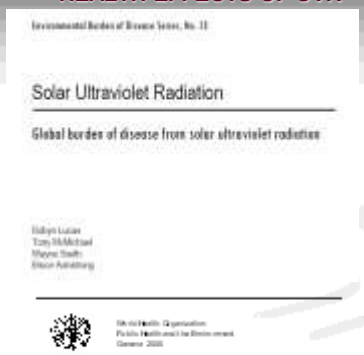
- ✓ Several occupations induce high exposure to UV, as agricultural workers (farmers, gardeners,…), construction workers (roofers, carpenters., …), road workers, fishermen, watermen, recreational workers (sky instructors, mountain guides, lifeguards, …), other, as police officers, military staff;
- ✓ In some, the activity is mainly/almost exclusively outdoor, other are mixed outdoor/indoor (as soldiers, policemen etc).
- ✓ URV exposure in outdoors workers is estimated 6 – 8 times higher than in indoor workers *(Gies et al, 2003)*

Measured Solar UV radiation exposure in groups of outdoor workers in Queenslands *(Gies and Wright, 2003)*

Exposure evaluated using film dosimeters (chest area, 4 hours) in 493 workers
Data expressed as Standard Erythemal Dose (SED) (CIE Res Note, 1987)
About 90 % exceeded the EL for occupational UVR exp, 50% four times or more



HEALTH EFFECTS OF UVR



EFFECTS ON THE SKIN

Acute

Sunburn
Photodermatoses

Chronic

Cutaneous malignant melanoma
Cancer of the lip
Basal cell carcinoma of the skin
Squamous cell carcinoma of the skin
Chronic sun damage/solar keratoses

(WHO, 2006)

EFFECTS ON THE EYE

Acute

Acute photokeratitis and conjunctivitis
Acute solar retinopathy

Chronic

Climatic droplet keratopathy
Pterygium
Pinguecula
Squamous cell carcinoma of the cornea
Squamous cell carcinoma of the conjunctiva
Cortical Cataract
Ocular melanoma
Macular degeneration

(WHO, 2006)

IMMUNE EFFECTS

Acute

Suppression of cell-mediated immunity
Increased susceptibility to infection
Impairment of prophylactic immunization
Activation of latent virus infection: herpes labialis

Chronic

Activation of latent virus infection: - papilloma virus
*Multiple sclerosis**
*Rheumatoid arthritis**
*Type 1 diabetes mellitus**

(WHO, 2006)

EFFECTS OF UV SOLAR RADIATION ON THE SKIN

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(WHO, 2006)

SUNBURN

Lautenschlager S. Lancet 2007

SUNBURN

- *Sunburn follows excessive exposure to UVR*
- *is the result of a **phototoxic** effect in the skin, unlike other types of "burns" (Fitzpatrick 1975; Hawk and Parrish 1982)*
- *erythema is **rarely detected before 4 hours**, and reaches a maximum at about 8 –12 h after exposure and fades within a few days*
- *is associated with a very **wide range of molecular and cellular changes**, including the appearance of inflammatory cells in the dermis (Hawk et al., 1988; Gilchrest et al., 1983), increasing p53 expression (Burren et al., 1998) and apoptosis (Sheehan and Young, 2002) in the epidermis. .*
- *Sunburn during childhood or during adulthood is a **recognized risk factor for melanom**a, and the risk increases with increasing number of sunburns (IARC, 1992)*

Sunburn is highly dose and wavelength dependent. Specific measurement quantities have been developed to describe sunburn sensitivity:

- *The Minimum Erythemal Dose (MED*) is the minimal UVR exposure producing a perceptible erythema after 4-24h; refers to a specific individual, as varies with UV spectrum, tanning capacity, adaptation
- *The Standard Erythemal Dose (SED)*: Standardised measure of erythemogenic UV radiation; 1 SED is equivalent to an erythemal effective radiant exposure of 100 joules per square meter ($J.m^2$) (ICNIRP 2010).
- *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 2001).*

Wide range of susceptibility to sunburn among individuals:

- Variuos types of skin, with different degrees of pigmentation can be classified into 1 of 6 sun-reactive skin types according to the scale first presented by Fitzpatrick (Fitzpatrick Skin Pigmentation scale)

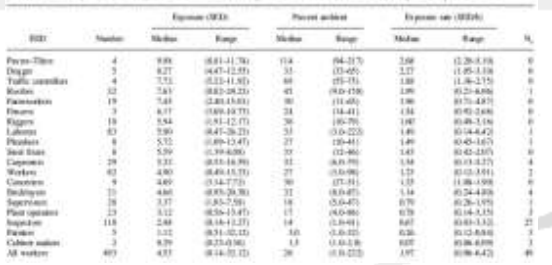
Classification of skin types based on their susceptibility to sunburn in sunlight and their ability to tan (from: ICNIPR 2010)

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.

Measured Solar UV radiation exposure in groups of outdoor workers in Queenslands *(Gies and Wright, 2003)*



P. Gies et al, 2003

Photoaging (Chronic sun damage/solar keratoses)

- ***Photoaging*** *complex of biologic processes affecting various layers of the skin with the* ***major damage seen in the connective tissue of the dermis;****. is the* ***result of chronic sun exposure****.*
- *Clinical symptoms include* ***dryness, wrinkling, elastosis, telangiectasia, and anomalous pigmentation****. Histologically,* ***the dermis is strikingly filled with on amorphous mass of deranged elastic fibers****. Collagen fibers are desorganized. Blood vessels are dilated and tortuous. Dermal inflammatory cells are increased. Keratinocytes are irregular with loss of polarity. Melanocytes are abnormal and decreased in number.*

UV SOLAR RADIATION AND THE SKIN: CANCER

Estimated number of cases of skin cancer diagnoses in U.S. in 2005: ***over 1 million, more than all other cancers combined****; the majority diagnosed with nonmelanoma skin cancer (NMSC), which includes basal cell (BCC) and squamous cell (SCC) carcinomas (Geller 2003; Ramirez, 2005). One in five Americans will develop skin cancer during their lifetime, (Riegel 2002)*

90% related to sun exposure *(Skin Cancer Foundation, 2009)*

The incidence of both non melanoma skin cancer (NMSC) and melanoma is increasing; melanoma is increasing more rapidly than any other reported cancer (Gloster, 1996; Ramirez 2005)

UV SOLAR RADIATION AND THE SKIN: CANCER

- *The World Health Organization has reported that* ***excessive solar UVR exposure results in 60,000 premature deaths per year worldwide****. Of these, an estimated 48,000 were the result of malignant melanomas and 12,000 were from skin carcinomas (V. Hammond et al, 2008).*
- *Although other environmental and genetic factors may contribute to the development of NMSC and melanoma,* ***UV exposure is considered the most important risk factor.***

UV SOLAR RADIATION AND SKIN CANCER: Occupational Exposure

Last Decade 19th Century:

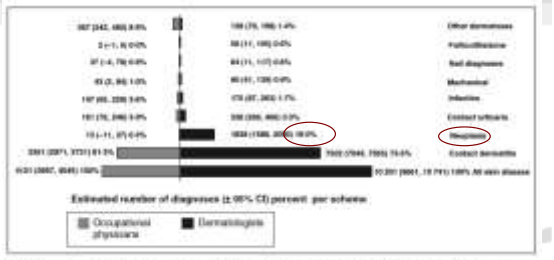
Unna observed sailor's skin carcinoma (Seeman-shautcarzinom), and reported precursor stages in chronically exposed skin, starting from hyperkeratosis (Unna, 1894)

Current knowledge

Role of occupational exposure demonstrated in various epidemiological studies in workers engaged in occupations inducing high UV exposure

SKIN DISEASE WORK RELATED

UK 2002/2005



Turner et al, 2007

Skin Cancer

Basal cell carcinoma of the skin

- causal relationship of UVR to BCC is firmly established (WHO, 2006)
- the causative pattern of UVR exposure seems to be quite different to that of SCC**: risk of is significantly increased in subjects with a history of sunburn** (*Hunter, 1990*) or other skin damage
- the risk increases with increasing occupational exposure, but particularly with increasing non-occupational or **intermittent exposure** to the sun (*Krickler, 1996*)
- is more common on those **body sites that are exposed intermittently to the sun,** rather than sites such as the back of the hand that are constantly exposed (*Sauter, 1998*)
- a large fraction of BCCs carry mutations in the p 53 suppressor gene which are typical of UVB damage (*de Gruijl, 2003*)
- there is some evidence that use of **sun protection devices reduces the risk of BCC** (*Robinson, 1992)*

Skin Cancer

Squamous cell carcinoma of the skin

- There is convincing epidemiologic and biological evidence of a causal association of UV exposure (particularly occupational exposure) to development of squamous cell carcinoma of the skin (SCC) *(WHO, 2006)*
- The site distribution corresponds to the **areas of greatest sun exposure;**
- increased risk related to **total lifetime sun exposure**, but particularly **occupational** sun exposure;
- **regular use** of broad spectrum **sunscreen can decrease the incidence of SCC;**
- association with solar keratoses
- evidence of mutation in p 53 gene (tumour suppressant) in response to UVR *(Kricker, 1994; Grossman, 1997; Armstrong, 2001; Sauter, 1998)*

Skin Cancer

Cutaneous Malignant Melanoma

- the lifetime risk for a person in the United States developing invasive melanoma was 1 in 1500 in 1935, 1 in 63 in 2007, and 1 in 33 *if in situ* melanomas are included (Siegel, 2008)
- **in Australia**, melanoma is currently **the third most commonly reported cancer** in men and women overall, and the commonest in women aged 17–33years (AIHV, 2008)
- mortality rates due to CMM, which increased in most European countries as well as in North America, Australia and New Zealand in the 1980s, peaked around 1990 and since then have tended to be stable, but probably due to early detection and treatment, rather than to primary prevention and changes in ambient UV radiation (Norval et al, 2011)

STANDARDIZED INCIDENCE AND MORTALITY FOR MALIGNANT MELANOMA IN UK (1975 – 2005)

Mackie R.M. et al. 2009

Skin Cancer

Cutaneous Malignant Melanoma

- little doubt from the epidemiologic literature that UVR has a causative relationship with development of malignant melanoma *(WHO, 2006)*
- positive association between **melanoma incidence and residence at lower latitudes**;
- **decrease** of the **risk** of melanoma in **those who migrated in childhood, from an area of low UVR to an area of high UVR** (compared to those born in the area of high UVR and still resident there)
- the body site distribution mirrors those areas of the body usually exposed to sunlight;
- a correlation with other solar skin damage (wrinkling, solar keratoses);
- melanoma incidence is very low of in people with black skin
- the **risk increases** (OR of the order of 1.5) with **a history of intermittent sun exposure and sunburn** *(reviewed in WHO, 1994; Armstrong, 1993)*.

EFFECTS ON THE EYES

Acute

Acute photokeratitis and conjunctivitis

Acute solar retinopathy *(sporadic)*

Chronic

Climatic droplet keratopathy
Pterygium
Pinguecula
Squamous cell carcinoma of the cornea
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Cortical Cataract
Ocular melanoma
Macular degeneration

(WHO, 2006)

Eye Effects

Acute photokeratitis and photoconjunctivitis

- experimental and epidemiological support the causative role of UVR in the development of acute photokeratitis and photoconjunctivitis *(Bergmanson, 1990; Kennedy, 1997; Sliney, 1987).*
- acute exposure to UVR in settings of high reflectance, such as surroundings covered by snow, is a common cause of photokeratitis (*snow blindness*)
- laboratory studies suggesting a mean threshold of UVB for photokeratitis of 3500Jm-2 *(reviewed in WHO, 1994)*
- UVB blocking contact lenses are able to prevent photokeratitis in laboratory animals *(Bergmanson, 1990)*

Eye Effects

Pterygium

Is a triangular shaped degeneration and hyperplastic process, due to an inflammatory, proliferative and invasive growth on the conjunctiva and cornea, that can impair vision.

Possibly due to UV radiation induced mutations in tumour suppressor genes, and the generation of damaging reactive oxygen radicals *(Detorakis and Spandidos, 2009)*

Eye Effects

Pterygium

- pterygium is associated with spending most of the time outdoors in childhood: RR 17.2 *(Mackenzie, 1992*)
- there is a negative latitudinal gradient for pterygium, but it is also common in arctic and sub arctic environments (*Cameron, 1965*).
- High prevalence in fishermen and sailors, exposed to relected UV radiation from the water *(Diffey, 2002*) and other epidemiological studies reporting an independent association with ocular UVR exposure *(WHO, 2006)*
- Threlfall et al's finding of a dose-response relationship between ocular UVR exposure pterygium provides further evidence of a causal association between UVR exposure and development of pterygium *(Threlfall, 1999)*

Eye Effects: Cataract

•It is estimated that there are 28,000 new cataract cases every day *(Sacca et al, 2009)*

•Represents an important cause of visual impairment in 30–40 million people

•The estimated number of blind people worldwide is 40 to 45 millions *(WHO, 2001,),* and the number of blind is expected to to double by the year 2025 *(Brian, 2001)*

•About 42 - 50% are currenty blind as a result of cataract *(Congdon et al, 2004; Gohdes et al, 2005)*

•Of these 16 - 22 millions, WHO estimates that as many as 5-20% is due to UV exposure *(WHO, 1999*)

•It is estimated that each 1% decrease in stratospheric ozone would result in an increase of 0.5% in the number of cataract related to solar UV *(WHO 1999)*

Eye Effects: Cataract

The three major types of cataract are cortical, nuclear and posterior subcapsular, but many are of a mixed type. While the distinction between the types is not always clearly made in (particularly older) epidemiological studies, the etiology of the different cataract types may be quite different

Nuclear cataract

EHC 160 assessed the evidence for nuclear cataract as showing no association between nuclear cataract and UVR exposure (1994)

Posterior subcapsular cataract (PSC)

While some studies have suggested a positive association between PSC cataract and UVB exposure using a number of different measures of UVB exposure, the weight of the evidence (particularly more recently) suggests that PSC cataract is not associated with increased UVB exposure *(WHO, 2004)*

Eye Effects: Cataract

Cortical cataract

- the evidence of an association between presence of cortical cataract and past ocular UVR exposure is largely consistent across a number of well-conducted, large studies *(WHO, 2006)*
- In Chesapeake Bay watermen, an increase of relative risk for presence of cortical cataract was found for the highest sun exposure category; the RR was three times that for the lowest exposure category (*Taylor, 1988)*
- in the Visual Impairment study in Victoria, Australia the risk of cortical cataract was increased (OR = 1.44, 95% CI 1.21 – 1.73). (McCarty, 1999).
- recent research focuses mainly on the biological processes involved, including the effects of timing and of repeated exposure (*Ayala, 2000*), age of exposure (*Dong, 2003*), the role of UVA in cataract genesis (*Zigman, 2005*), and protective mechanisms (*Colitz, 2005*).

CONCLUSIONS

- **over 1 million of skin cancer (the majority nonmelanoma skin cancer, diagnosed in 2005 in U.S, more than all other cancers combined; 90% considered related to sun exposure**
- **excessive solar UVR exposure results in 60,000 premature deaths per year worldwide, 48,000 from malignant melanomas and 12,000 from skin carcinomas**
- **the incidence of both non melanoma skin cancer (NMSC) and melanoma is increasing; melanoma is increasing more rapidly than any other reported cancer**

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- **the incidence of both non melanoma skin cancer (NMSC) and melanoma is increasing; melanoma is increasing more rapidly than any other reported cancer**
- **16- 22 millions of blind as a result of catact (2000), and the number is expected to double by the year 2025: as many as 5 - 20 % are due to UV exposure**
- **It is estimated that each 1% decrease in stratospheric ozone would result in an increase of 1-2% of melanoma mortality and 0.5% in the number of cataract**

CONCLUSIONS

- **a significant reduction of UV occupational exposure is possible, as shown various reports of intervention programs in different groups of workers**
- **the reduction of UV exposure proved effective in the reduction of UV adverse effects**
- **epidemiological data suggest that in implementing sun protection**
  - **intermittent exposures, not only total exposure, have an important impact**
  - **sun protection will have the greatest impact if achieved as early as possible in life**
  - **it will probably have an impact later in life, especially in those who had high childhood exposure to solar radiation**

CONCLUSIONS

- **Up now, with few notably exception, the problem of UV radiation occupational exposure has apparently raised insufficient attention, especially in employers and workers**
- **Data show that effective interventions to improve sun protection in outdoor workers are feasible**
- **An additional effort is urgently needed**