SOLAR UV RADIATION AS A *DOUBLE FACE* ENVIRONMENTAL POLLUTANT.

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Abstract: The somehow ambiguous role of solar UV radiation in its potentially dangerous and beneficial effects on human health is documented. A short critical overview of the indicators presently used to quantify the ambient and the biologically effective UV radiation is provided, as well as a discussion of the appropriate measurement strategies. The results obtained by the GMET research group (Sapienza Rome University) on the quantification by PS dosimetry of UV exposure of workers in different outdoor occupational activities are illustrated. Finally, a widespread information on the beneficial and damaging effects of UV exposure, taken together with a better understanding of the effects of occupational exposure, is indicated as extremely useful in designing targeted and effective prevention strategies.

1 INTRODUCTION

Physical agents, potentially pollutants of the environment, are factors controlled by physical relationships which can determine variations for life and for working environmental conditions, with implications on human health. Among such physical agents, ultraviolet (UV) radiation is considered one of the most important . Current evidence suggests that this agent is the major cause of several short and long term skin and eye diseases. Notwithstanding the adverse effects, solar UV radiation is responsible of the vitamin D synthesis necessary for skeletal health. In addition, adequate vitamin D levels have been suggested as a beneficial factor against breast, prostate and colon cancer.

This duality of UV radiation calls for a better knowledge of UV exposure in order to adopt proper sun-related behaviour, to maximise vitamin D production, and to reduce harmful effects.

2 FACTORS AFFECTING AMBIENT UV RADIATION

Solar UV radiation (direct beam) in the atmosphere is subject to the Beer-Lambert law which states that: the greater the amount of absorbing material encountered by radiation on its path, the smaller the amount of radiation reaching the surface. The amount of solar UV (200-400 nm) radiation is mainly controlled by oxygen and ozone (O_3) in the middle and upper atmosphere, resulting in complete absorption of UVC band. At the Earth's surface UV region comprises only a few percent of global radiation, approximately 6-7% in the UVA (320-400 nm) region and less than 1% in the UVB band (280-320 nm). UV atmospheric attenuation is not only due to the absorption process, but also depends on Rayleigh scattering by air gases and Mie scattering by aerosol. In addition, the 27-day apparent solar rotation and the 11-year cycle of sunspot activity, together with

the variable Earth-Sun distance, slightly affect the terrestrial UVB and UVA radiation. Other relevant factors can interact synergistically with UV radiation, making its knowledge a difficult task. Surface albedo, altitude, solar zenith angle (which in turn depends on latitude and the time of day) and local atmospheric composition (tropospheric gases, cloud cover and particulate) are responsible of large seasonal and geographical surface UV variability.

The influence of some of these factors on UV levels is complex to quantify due, in particular, to the effects of clouds which depend, at any given wavelength, upon the fraction of the sky covered by clouds and on the composition of the latter. The nonlinear influence of altitude on UV irradiance cannot be described by a single figure since it depends on a combination of several factors such as reduction of scattering and absorption, clouds effects, tropospheric ozone, albedo (Seckmeyer et al., 1997, WMO 2006) and wavelength.

In the troposphere UV radiation controls the chemical reactions involved in ozone formation, which in turn can attenuate up ~ 20% UV radiation at surface (Mckenzie et al. 2008.). There are other tropospheric absorbers such as sulphur dioxide, nitrogen dioxide and many organic species which attenuate surface UV radiation in polluted areas. The UV increase from ozone depletion may be balanced, at a certain degree, by the concentration of tropospheric gases and other air pollutants (WMO, 2007). In the last Ozone Assessment (WMO, 2007), the absorption sensitivity parameter as calculated by Chubarova (2006) is reported. This parameter expresses the relative UV changes due to 1-DU (Dobson Units) change in O_3, nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) concentration in the lower troposphere (Table 1).

Table 1: UV changes (%) due to 1-DU O_3, NO_2, SO_2 change in the lower troposphere

	O_3		NO_2		SO_2	
	July	January	July	January	July	January
UVB (280-315nm)	-0.3	-0.4	-0.8	-1.5	-0.6	-0-8
UVA (315-400nm)	negligible		-1.6	-3.0	negligible	
UV (280-400nm)	negligible		-1.6	-2.9	negligible	

Furthermore, the air pollution in the boundary layer, typical of urban sites, affects the retrieved satellite–based surface UV irradiances because aerosol absorption is not accounted for in the current satellite algorithms, which then results in UV overestimation (Ialongo et al., 2008,. Arola et al., 2009). However, in the last years progress in the understating of the modulating surface UV factors has been achieved through more sophisticated transfer models and higher quality UV measurements.

3 THE BIOLOGICALLY EFFECTIVE UV RADIATION

The common evidence of the short term deterministic response to UV exposure is erythemal reaction, i.e. cutaneous inflammatory reaction to excessive solar UV exposure (Norval et al., 2007), mainly in fair, lightly pigmented skin types. There are other acute injuries such as photodermatoses, immunosuppression, phototoxicity/photoallergy and pigmentation (tanning). UV radiation has also the ability of both initiating and exacerbating skin cancer (chronic effects), due to DNA damage and mutation of the p53 gene. This is considered as a specific outcome of UV exposure at the molecular level, together with some eye pathologies. In 1992 the International Agency for Research on Cancer (IARC) classified solar radiation in class 1 as carcinogenic agent to humans, as suggested from the results of several epidemiological and experimental studies. On the other hand, the primary source of vitamin D in humans derives from sunlight exposure, which is then highly beneficial for bone growth and health. In addition, several recent studies suggest the possible protective role of vitamin D in several diseases and even in some neoplasias of internal organs (Grant and Holick, 2005, Holick, 2007; Springbett et al., 2010).

To assess any healthy effects, knowledge of the appropriate action spectra is required. The most employed action spectra provided by the International Commission on Illumination (CIE) are those concerning erythema (CIE, 1998) and the initiation of synthesis of pre-vitamin D_3 in skin (CIE, 2006). The latter is an updated version of that proposed by McLaughlin et al.,1982) who used an *in vivo* technique and which contains an extrapolation of an earlier version from 315 nm to 330 nm. Recently Norval et al. (2010) discussed in detail the uncertainty of pre-vitamin D_3 action spectrum, both that obtained by McLauglin (1982) and that suggested by CIE (2006). As underlined also by MacKenzie et al. (2009), further experimentation is needed to determine more accurately the UV role in photoconversion of pro-vitamin D_3 to pre-vitamin D_3. in human skin.The above mentioned action spectra are both used to weight solar UV spectral radiation for each wavelength. The integration of weighted irradiances over the UV region yields the erythemal and pre-vitamin D_3 effective integrated irradiance (or dose rate), respectively. It ought to be noticed that the action spectrum does not take into account any spectral interaction.

Figure 1 shows the erythemal (CIE, 1998) and pre-vitamin D_3 synthesis (CIE, 2006) action spectra together with a typical clear sky UV spectrum measured at Rome (41.9°N; 12.5°E, 75 m a.s.l.), at local noon time during the summer and winter solstices. These days were chosen in order to have similar daily total ozone average (toz = 317 DU in winter day and toz=325 DU in summer). It should be noticed that the difference between the two solar spectra is due to the larger solar zenith angle (SZA = 66.7°) in winter than in summer (SZA = 18.6°).
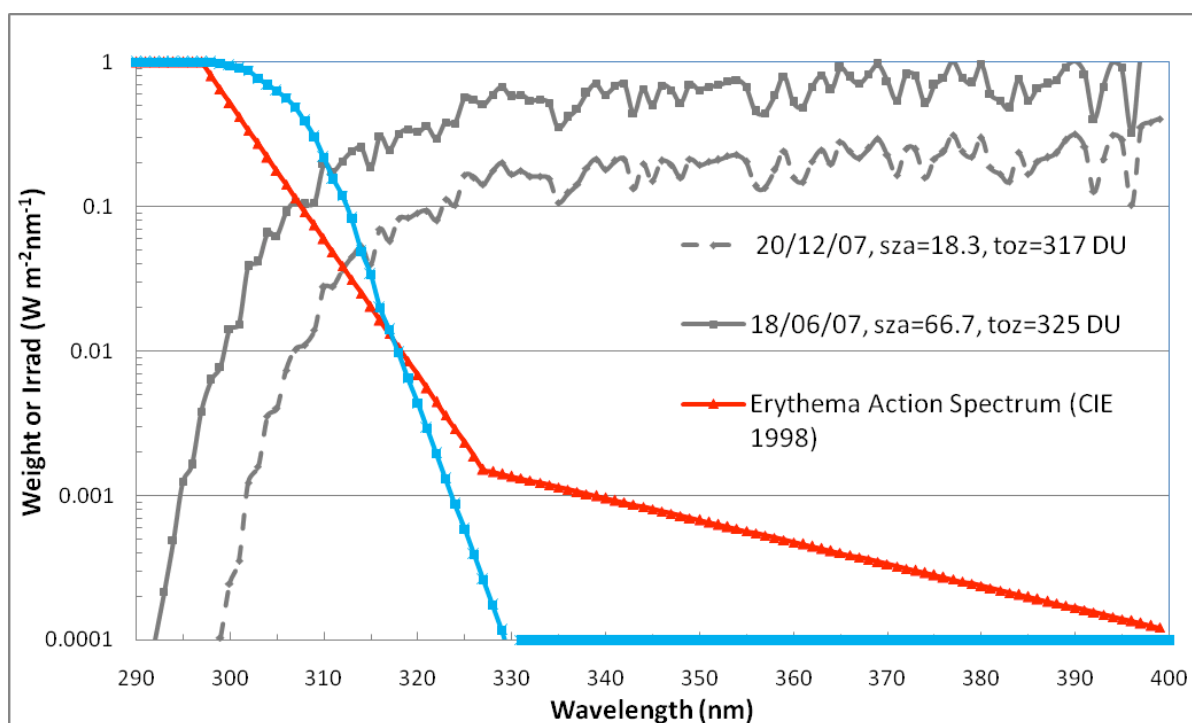

Figure 1: Semi-log plot of erythema (red line) and pre-vitamin D_3 synthesis (blue line) action spectrum together with a typical clear sky UV spectrum measured at Rome (41.9°N; 12.5°E, 75 m a.s.l) at local noon time, near the summer (solid line) and winter (dotted line) solstices. Both spectra and total ozone are measured by a Brewer spectrophotometer #067.

It is worth reminding that the biologically effective irradiances, as measured by spectrophotometers and/or radiometer, give UV radiation incident on a horizontal surface (here called ambient UV) taking into account neither the body geometry nor the physiological effects. The erythema and pre-vitamin D_3 action spectra are normalized to unity at 298 nm. Both action spectra show the maximum effectiveness at shorter wavelengths, but it is to be noticed a lower contribution from 299-315 nm for the former one. Furthemore, the erythema extends to 400 nm (UVA region) while the pre-vitamin D_3 action spectrum stops at 330 nm.

The pre-vitamin D_3-weighted spectral UV irradiances are larger than the erythemal-weighted ones in summer (Figure 2). The integration of weighted irradiances over the UV wavelengths is 0.22 W/m^2 for erythema and 0.44 W/m^2 for pre-vitamin D_3. In contrast, the difference between the two weighted irradiances are not remarkable in winter. This seasonal behaviour is attributable to the lower SZA in summer, where the shorter wavelengths dominate, and to the bigger contribution in UVB region of the pre-vitamin D3 weights. The contribution in UVA band is small for both spectra, mainly for pre-vitamin D_3 dose rate.

The diurnal behaviour of the ratio between pre- vitamin D_3 and erythemal ambient dose rate during a winter and summer day is plotted in Figure 3. Notice that: at midday the pre-vitamin D_3 dose rate is twice the erythemally dose in summer, while in winter the ratio is less than 1.5. The relationship between the two biologically effective quantities is not linear, being the UVB weight contributions different in the two spectra. A conversion should be derived in function of total ozone and SZA (Pope et al., 2008, Parisi et al., 2009; McKenzie et al., 2009).
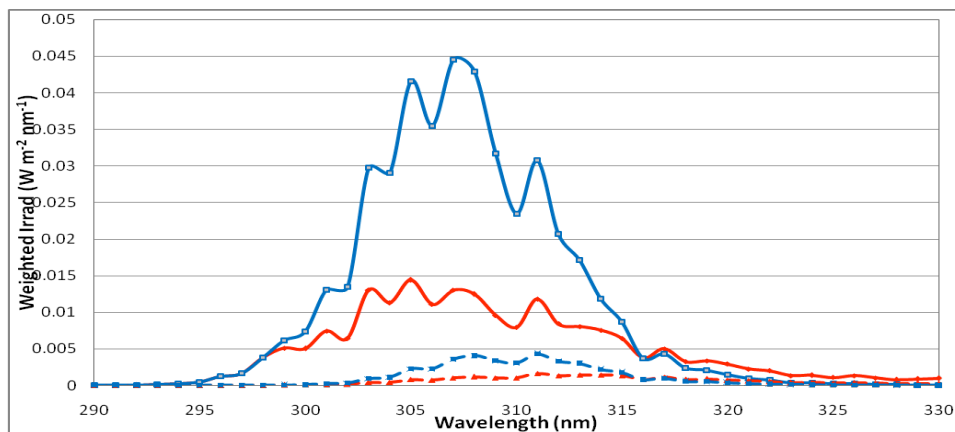

Figure 2: Spectral erythema (red line) and pre-vitamin D_3 (blue line) weighted irradiance close to the summer (18/06/ 2007, solid lines) and winter (20/12/2007, dashed lines) solstices.
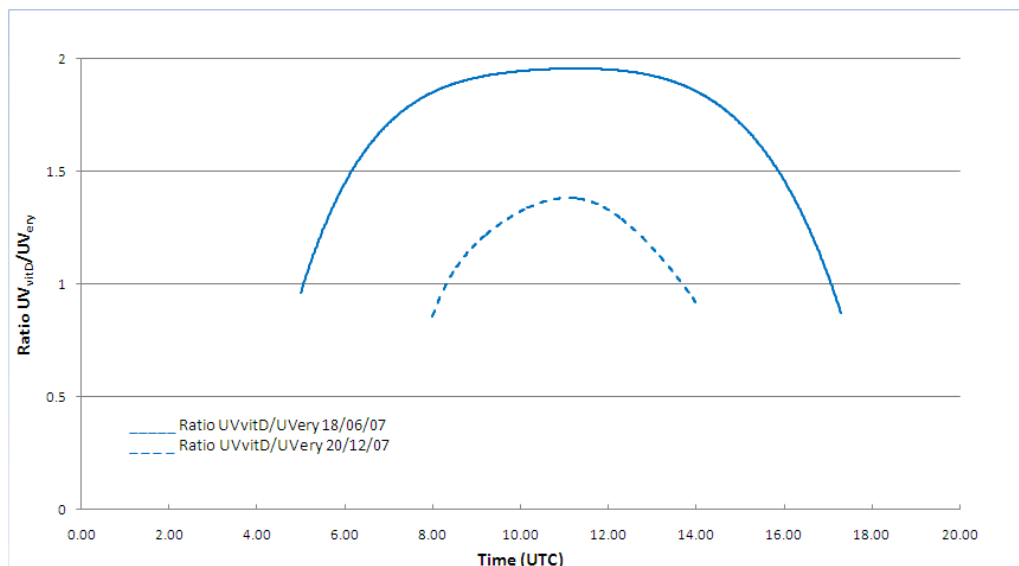

Figure 3: Diurnal variation of the ratio between pre-vitamin D and erythemal dose rate in a summer (solid curve) and a winter day (dashed curve).

4 ERYTHEMAL AND PRE-VITAMIN D$_3$ EXPOSURE

The majority of solar UV biologically effective radiation consists traditionally of ambient erythemally weighted UV irradiance, measured by well-calibrated instruments such as spectroradiometers, broad-band and narrow-band radiometers. In order to facilitate the adoption of suitable sun exposure habits, the UV index is generally provided, an adimensional quantity derived by measurements or modelling of ambient erythemally weighted UV irradiance (in Wm^{-2}) multiplying by 40 (WHO, 2002). However, the UV index is of limited value because specific body parts can be overexposed receiving much higher UV doses than others (Siani et al., 2008, Casale et al., 2009). Moreover, besides the geometry of the exposed anatomical parts and the ambient UV irradiance, additional factors should be taken into account , such as the individual photosensitivity, occupational / leisure activity, duration of exposure and use of personal protection (clothing, sunscreens etc.). In contrast, inadequate exposure to UV radiation can lead to the lack of cutaneous syntesis of vitamin D. The scientific debate, regarding the duality of UVR on human health and the search for the optimal UV exposure without detrimental effects of any kind, is still ongoing (Diffey, 2006; Kimlin and Tenkate, 2007).
To describe sunburn susceptibility the Minimum Erythemal Dose, MED (i.e. the dose necessary to produce erythema 8-24 hours after exposure) is adopted. This quantity depends on the sensitivity of different skin types to UV radiation. The Fitzpatrick scale provides the most common classification (Fitzpatrick et al., 1988), based on the observation of hair and eye colours, skin pigmentation, burning and tanning tendency. In Table 2 the MEDs required to induce erythema for each skin type are reported.
To avoid the dependence from the skin type the CIE Standard Erythemal Dose (SED) was introduced, defined as an erythemal effective exposure equivalent to 100 J/m^2 (CIE, 1998). One SED is about half of necessary dose to produce erythema in skin type-1.

Table 2: Classification of skin types and MED required to induce the erythema (Fitzpatrick et al., 1988). Standard vitamin D dose, SSD (Webb and Engelsen 2006), are reported in the forth column

Skin Type	Skin Color	MED (Jm^{-2})	SSD (Jm^{-2})
I	White; very fair; red or blonde hair; blue eyes; freckles	200 - 300	37.2
II	White; fair; red or blonde hair; blue, hazel, or green eyes	250 - 300	46.5
III	Cream white; fair with any eye or hair color; very common	300 - 500	55.8
IV	Brown; typical Mediterranean Caucasian skin	450 - 600	83.6
V	Dark Brown; mid-eastern skin types	600 - 1000	111.4
VI	Black	1000	185.1

In Table 3 the exposure times concerning erythema for each UV index and for each skin type, are given. These times were calculated taking into account the MED range (Table 2) of each skin type.
As for the occupational exposure, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines for eye and skin recommended a threshold limit value of 30 Jm^{-2} per 8-h work, equivalent to 1-1.30SED if CIE erythema action spectrum is used. An interesting issue concerns whether the threshold limit to protect outdoor workers will be steadily applied. In any case, a better understanding of effective occupational exposure would be extremely useful in designing targeted prevention strategies
As for the minimum UV exposure required for vitamin D production, Webb and Engelsen (2006) estimated the standard vitamin doses (SSD) for skin types based on ¼ exposed body area, corresponding to a UV equivalent of an intake of 1000 IU vitamin D, and using as reference a spring midday solar spectrum at a mid-latitude site. The SSDs are reported in Table 2, fourth column. Recently Dowdy et al., (2010) showed that Webb's SSDs overestimate by about 1/3 UV exposure equivalent to 1000 IU. Thus, more work is needed to define the proper doses for optimal vitamin D production.

Table 3 reports the exposure time (min) to induce erythema as function of UV index for each phototype.

UVI	Phototype I	Phototype II	Phototype III	Phototype IV	Phototype V -VI
1	133 -200	167-200	200-333	300-400	400-1333
2	67-100	83-100	100-167	150-200	200-667
3	44-67	56-67	67-111	100-133	133-444
4	33-50	42-50	50-83	75-100	100-333
5	27-40	33-40	40-67	60-80	80-267
6	22-33	28-33	33-56	50-67	67-222
7	19-29	24-29	29-48	43-57	57-190
8	17-25	21-25	25-42	38-50	50-167
9	15-22	19-22	22-37	33-44	44-148
10	13-20	17-20	20-33	30-40	40-133

5   POLYSULPHONE DOSIMETRY IN OUTDOOR OCCUPATIONAL ACTVITIES

Since in the human body different anatomical parts are quite differently orientated, only personal dosimetry enables qppropriate estimates of the actual exposure . A dosimeter is calibrated in physical or biologically effective units against another instrument measuring UV irradiance (spectroradiometer or radiometer). Polysulphone (PS) dosimetry was used in several studies for a reliable quantification of the erythemally effective UV dose received by an anatomical site (Parisi et al., 2000; Kimlin, 2003). The PS polymer is endowed with a response to UV radiation similar to that of human skin and photodegrades with a measurable absorbance; thus, only a calibration is necessary to compensate the difference between PS and skin responses. Moreover, PS dosimetry is sensitive enough to detect UV pollution levels and differences, if any, between urban and non-urban human acitivties characterized by similar exposure conditions.

The GMET research group of the Sapienza Università di Roma is carrying out a careful study on the quantification of UV exposure using PS dosimetry (Casale et al, 2006; Siani et al, 2008; Siani et al, 2009; Casale et al., 2009). In order to assess the variability of solar UV personal exposure, three experimental campaigns were carried out in 2005 on vineyard workers at the rural site of S. Felice (nearby Siena) in Tuscany, Italy (Lat.43.3°N, Long.11.3°E, altitude 300m). The first field campaign was performed in April, at the beginning of the working season; the second one in July, when the sun irradiance reaches its maximum level; the last one in October, at the end of the outdoor working season. The above periods were selected since they refer to different activities and hence different working postures. Each volunteer wore two PS dosimeters: one on his arm and the other on his back. A total number of 34 adults (27 male and 7 female) aged

18-60 years participated in the campaigns: 13 males and 2 females with photo-type II, 14 males and 4 females with photo-type III and one female with photo-type IV. The UV index ranged between 0.3 and 6.0. (April), between 0.0 - 9.0 (July) and 0.0-3.0 (October). The preliminary results are summarized in Table 4.

Table 4: Doses received on the back of neck and on arm for each photo type group in terms of median (minimum and maximum in brackets).

	Photo-type II		Photo-type III-IV	
Dose (SED)	Neck	Arm	Neck	Arm
spring	13.9(10.5-19.9)	10.8 (7.1-14.2)	16.4(12.5-20.7)	10.4 (7.7-12.8)
summer	17.8(13.8-21.1)	11.3 (8.5 -13.1)	16.4(11.8- 21.2)	10.9 (5.9-15.6)
Fall	3.0 (1.8-3.2)	2.0 (1.3-2.7)	2.7 (2.3- 3.6)	2.0 (1.3-2.3)

It should be noticed that: 1) personal doses were always above the recommended threshold value of 1- 1.3 SED /8h, and 2) the measured doses exceed the MED (2.5 -6 SED) in spring and summer for all photo-types under study. This study is still in progress.

6   CONCLUSIONS

The discovery of stratospheric ozone depletion, produced in recent years a noticeable increase in the number of UV studies leading to a deeper scientific knowledge and quantification of the factors affecting UV transmission through the atmosphere. Although the ozone downward trend was well established, its impact on UV in unpolluted sites was estimated to be a few percentage per decade. The strong influence of clouds and of variation in aerosol concentration affect largely the variability of UV radiation at the surface, mainly in polluted sites. Consequently, the future UV scenario is highly uncertain.

Moreover, given the dangerous/beneficial health consequences of UV radiation, to define optimal sun exposure levels an accurate quantification of individual exposure is required under a wide variety of environmental and personal conditions. A critical analysis of the currently used risk index (UV index), which only provides information on erythemal effects of ambient radiation, is also needed to clarify the importance of risks/benefits balance of solar UV radiation. Finally, it is difficult to overestimate the importance of a widespread information on the beneficial/damaging effects of UV exposure and, at any rate, a better understanding of the consequences of occupational exposure, will show useful in designing targeted and effective prevention strategies.

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