BS EN 14255-3:2008

Measurement and assessment of personal exposures to incoherent optical radiation —

Part 3: UV-Radiation emitted by the sun

ICS 17.240

British Standards

National foreword

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Messung und Beurteilung von personenbezogenen Expositionen gegenüber inkohärenter optischer Strahlung - Teil 3: Von der Sonne emittierte UV-Strahlung

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Foreword

This document (EN 14255-3:2008) has been prepared by Technical Committee CEN/TC 169 "Light and lighting", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2008, and conflicting national standards shall be withdrawn at the latest by September 2008.

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EN 14255 *Measurement and assessment of personal exposures to incoherent optical radiation* is published in four parts:

— *Part 1: Ultraviolet radiation emitted by artificial sources in the workplace*

— *Part 2: Visible and infrared radiation emitted by artificial sources in the workplace*

— *Part 3 (this part): UV-Radiation emitted by the sun*

— *Part 4: Terminology and quantities used in UV-, visible and IR-exposure measurements*

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

People may be exposed to ultraviolet (UV) radiation emitted by artificial or natural sources. The most important natural source for UV-radiation exposure is the sun. Depending on global factors such as geographical position, season, time of day, altitude, cloudiness and individual factors such as clothing, the time spent outdoors may result in a significant UV-exposure to the sun.

Exposure to ultraviolet radiation from the sun is of considerable health concern. UV-exposure can produce both beneficial and harmful health effects. Vitamin D production is recognized as a beneficial effect. Acute harmful effects on the eyes and the skin can be induced by short term UV-irradiation of high intensity. Typical injuries are photoconjunctivitis and photokeratitis of the eye and UV-erythema of the skin. Minor doses of UV-radiation may induce or aggravate some diseases such as porphyria or lupus erythematosis or may trigger phototoxic and photoallergic reactions.

The visible and the infrared part of the radiation spectrum of the sun may also cause short term injuries, when overexposure occurs, such as thermal damage to the skin as well as thermal and photochemical injuries of the retina of the eyes. However, visible and infrared radiation exposures are not dealt with in this standard.

Additionally, long term UV-irradiation may result in damage to the eyes and skin, such as cataracts, skin aging and skin cancer. There is also increasing evidence that UV-exposure suppresses the immune system, which could lead to a reduction in the efficacy of immunization programmes and increase the spread of infectious diseases. Between two and three million non-melanoma skin cancers are diagnosed worldwide each year which are rarely fatal and can be surgically removed; approximately 132,000 melanoma skin cancers occur globally each year. Melanoma is responsible for approximately 80 % of an estimated 66,000 deaths annually due to skin cancer [1].

Worldwide some 12 to 15 million people become blind from cataracts annually, of which up to 20% may be caused or aggravated by sun exposure, according to estimates by the World Health Organization (WHO). These numbers will increase as the stratospheric ozone layer is depleted over the next decades, unless people become aware of the hazards of UV-radiation exposure, especially from the sun [2].

In order to avoid short term injuries and reduce additional risks from long term UV-exposures international recommendations advise restriction of solar UV-exposures [3]. To achieve this, it is necessary to determine the level of solar UV-exposure and assess its gravity. Such determination can be achieved either by measurements or by estimations.

This European Standard supports the application of recommendations of international or European organisations (e. g. WHO, ICNIRP[1)] , EUROSKIN) for protection against harmful solar UV-exposure.

This standard specifies procedures for the measurement or estimation and the assessment of solar UV-exposures. For radiation protection purposes it is not always necessary to determine exactly the personal solar UV-exposure. Often a more general determination of the solar UV-exposure level is sufficient. The UV-Index is one of the means for that. The UV-Index can describe the current measured, the expected daily maximum, or the expected daily trend of the erythemally effective irradiance. It is based on regional measurements or calculations of the global solar radiation. It is published by various organisations and in weather forecasts. It can be used to forecast the expected solar UV-exposure and to plan protective measures, if necessary. So it is a means to determine an approximate personal solar UV-exposure. As the UV-Index is usually determined for a larger regional area the local solar UV-exposure may deviate due to different cloud cover and other reasons. So the local and individual UV-exposure assessment has to be adjusted accordingly.

1) ICNIRP International Commission on Non-Ionizing Radiation

A similar approach is the determination of the skin and ocular exposure factors [4, 5]. It allows an approximate local solar UV-exposure estimation. As it is not based on measurements the uncertainty may be larger than an estimation based on the UV-Index. However this method does take local factors (cloud cover, albedo) and individual factors (clothing and protective measures) into account.

For the planning of solar UV-radiation protection purposes when travelling, a calculation of the global solar radiation exposure depending on season, time of day, geographical position, etc. may be helpful. There are software programs which allow such calculations.

In some cases it is necessary to determine the personal solar UV-exposure more exactly. This can be done by measurements of the erythemal and/or the non-melanoma skin cancer radiant exposure. These exposure data can be used to determine individual risks.

Personal solar UV-exposures can in some cases also be determined by UV-exposure measurements according to EN 14255-1. The results can be compared to recommended or required limit values in order to assess the gravity of the exposure.

When the solar UV-exposure exceeds a certain level it may be necessary to apply protective measures in order to avoid injuries of the skin and the eyes. This standard does not specify sun protection measures but gives corresponding reference sources.

1 Scope

This European Standard specifies procedures for the measurement or estimation and the assessment of personal exposures to ultraviolet radiation emitted by the sun.

NOTE 1 According to CIE 17.4 UV-radiation is defined as an electromagnetic radiation with wavelength between 100 nm and 400 nm. Due to atmospheric absorption only solar UV-radiation in the spectral region between 280 nm and 400 nm reaches the earth's surface in significant amounts.

This European Standard applies to solar UV-exposures when staying outdoors.

This European Standard is applicable to workers and to the general population.

This European Standard does not apply to UV-exposures caused by artificial sources, e.g. UV-lamps, welding arcs.

NOTE 2 Part 1 of this European Standard deals with UV-exposures caused by artificial sources.

NOTE 3 For radiation emissions of products other standards apply, such as CIE S 009 for lamps and lamp systems, EN 60335-2-27 [6] for sunbeds, EN 60335-2-59 [7] for insect killers and EN 12198 [8] for radiation emissions of machinery.

This European Standard does not apply to radiation exposures which concern the retina of the eyes.

NOTE 4 Ultraviolet and visible radiation exposures of the eyes may result in photochemical damage to the retina (this is often called the blue light hazard). The associated action spectrum contains mainly visible radiation and only a very small contribution in the ultraviolet region. The determination and assessment of radiation which may result in a blue light hazard may be done in accordance with part 2 of EN 14255 [20].

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 14255-1:2005, *Measurement and assessment of personal exposures to incoherent optical radiation — Part 1: Ultraviolet radiation emitted by artificial sources in the workplace*

EN 14255-4:2006, *Measurement and assessment of personal exposures to incoherent optical radiation — Part 4: Terminology and quantities used in UV-, visible and IR-exposure measurements*

CIE S 013, *International standard global solar UV-Index*

CIE 17.4, *International lighting vocabulary; Chapter 845: lighting*

CIE S 019, *Photocarcinogenesis Action Spectrum (Non-Melanoma Skin Cancers)*

ISO/CIE 17166, *Erythema reference action spectrum and standard erythema dose*

3 Terms and definitions

3.1 Symbols, terms and units

For the purposes of this document, the terms and definitions given in EN 14255-4:2006 and the following apply.

Table 1 — Symbols, terms and units

Symbol	Term	Unit	Defined in
λ	wavelength	nm	CIE 17.4 ref 845-01-14
λ_1 , λ_2	boundaries of a wavelength-range $\Delta\lambda$	nm	EN 14255-4
Δt_{exp}	exposure duration	s	EN 14255-4
E	irradiance	W/m²	CIE 17.4 ref 845-01-37
$E_\lambda(t,\lambda)$, $E_\lambda(\lambda)$	spectral irradiance	W/(m²·nm)	EN 14255-4
H	radiant exposure	J/m²	CIE 17.4 ref 845-01-42
$H_\lambda(\lambda)$	spectral radiant exposure	J/(m²·nm)	EN 14255-4
E_s	ultraviolet hazard irradiance	W/m²	EN 14255-4
H_s	ultraviolet hazard radiant exposure	J/m²	EN 14255-4
$s(\lambda)$	ultraviolet hazard weighting function	—	EN 14255-4
I_{UV}	solar UV-Index	—	CIE S 013
f_{SE}	skin exposure factor	—	3.2.2
$s_{er}(\lambda)$	erythemal weighting function	—	ISO/CIE 17166
E_{er}	erythemal effective irradiance	W/m²	ISO/CIE 17166
H_{er}	erythemal effective radiant exposure	J/m²	ISO/CIE 17166
SED	standard erythema dose	—	3.2.6
MED	minimal erythema dose	J/m² or SED	3.2.7
$s_{nmsc}(\lambda)$	non-melanoma skin cancer weighting function	—	CIE S 019
E_{nmsc}	non-melanoma skin cancer irradiance	W/m²	EN 14255-4
H_{nmsc}	non-melanoma skin cancer radiant exposure	J/m²	EN 14255-4

3.2 Definitions

3.2.1
solar UV-Index
I_{UV}
quantity which expresses the erythemal potential of the terrestrial solar UV-radiation, incident on a horizontal plane, given by

$$I_{\mathrm{UV}} = \mathrm{k}_{\mathrm{er}} \cdot \int_{250nm}^{400nm} E_{\lambda}(\lambda) \cdot s_{\mathrm{er}}(\lambda)\, \mathrm{d}\lambda \qquad (1)$$

where

$E_{\lambda}(\lambda)$ is the solar spectral irradiance

$s_{\mathrm{er}}(\lambda)$ is the erythemal weighting function as specified by ISO/CIE 17166

k_{er} is a constant equal to 40 m^2/W.

NOTE 1 The UV-Index is quoted to the nearest whole integer value. The irradiance measurement is carried out on an unobstructed horizontal plane e.g. on top of a building.

NOTE 2 This is a simplified definition. More information about the international standard global UV-Index can be found in CIE S 013 which is based on the recommendations of WHO/WMO/UNEP/ICNIRP [3].

NOTE 3 The solar UV-Index was developed as a simple scale for the public domain and for public information about the risk of erythema and related hazards from solar exposures. It is used e.g. in weather forecasts.

3.2.2
Skin exposure factor
f_{SE}
quantity that estimates the severity of solar UV skin exposure accounting for environmental and individual variables, given by

$$f_{\mathrm{SE}} = f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot f_5 \cdot f_6 \qquad \text{(see [4], [5])} \qquad (2)$$

where

f_1 is the factor depending on geographical latitude and season;

f_2 is the factor depending on cloud cover;

f_3 is the factor depending on duration of exposure;

f_4 is the factor depending on ground reflectance;

f_5 is the factor depending on clothing;

f_6 is the factor depending on shade.

3.2.3
erythemal effective radiant exposure
H_{er}
radiant exposure spectrally weighted with the erythemal weighting function $s_{\mathrm{er}}(\lambda)$, given by:

$$H_{er} = \int_{\Delta t_{\mathrm{exp}}} \int_{250nm}^{400nm} E_{\lambda}(\lambda) \cdot s_{er}(\lambda) d\lambda dt \qquad (3)$$

or:

$$H_{\mathrm{er}} = \int_{\Delta t_{\mathrm{exp}}} E_{\mathrm{er}}(t) \mathrm{d}t \qquad (4)$$

where

$E_\lambda(\lambda)$ is the spectral irradiance;

E_{er} is the erythemal effective irradiance;

$s_{er}(\lambda)$ is the erythemal weighting function;

Δt_{exp} is the exposure duration.

NOTE The erythemal effective radiant exposure is defined, from 250 nm to 400 nm, in ISO/CIE 17166

3.2.4
erythemal weighting function
$\boldsymbol{s_{er}(\lambda)}$
spectral weighting function reflecting the erythemal effect of ultraviolet radiation on the skin.

NOTE 1 The definition is derived from ISO/CIE 17166. CIE uses a slightly different name: *"*erythema action spectrum*"*. Values for this function are specified in ISO/CIE 17166 within a wavelength range from 250 nm to 400 nm.

3.2.5
standard erythema dose
SED
standardised measure of the erythemal effective radiant exposure H_{er}

NOTE 1 1 SED is equivalent to an erythemal effective radiant exposure of 100 J/m². SED is used as a unit in order to express the minimal erythema dose of an individual person, e. g.: 1 *MED* = 2,5 SED.

NOTE 2 The definition of the standard erythema dose is derived from ISO/CIE 17166.

3.2.6
minimal erythema dose
MED
measure of the erythemal effective radiant exposure that produces a just noticeable erythema on the skin of an individual person

NOTE The *MED* is a subjective measure based on the reddening of the skin; it depends on many variables, e. g. individual sensitivity to UVR, radiometric characteristics of the source, skin pigmentation, anatomic site, elapsed time between irradiation and observing the reddening (typical value: 24 h), etc. (taken from ISO/CIE 17166). It should be reserved solely for observational studies in humans and animals. The *MED* is either expressed in J/m² or in SED.

3.2.7
non-melanoma skin cancer weighting function
$\boldsymbol{s_{nmsc}(\lambda)}$
spectral weighting function reflecting the spectral dependency of the risk of causation of non-melanoma skin cancer by UV-exposure.

NOTE Values for this function are specified in CIE S 019 within a wavelength range from 250 nm to 400 nm.

3.2.8
non-melanoma skin cancer irradiance
$\boldsymbol{E_{nmsc}}$
irradiance spectrally weighted with the non-melanoma skin cancer weighting function $s_{nmsc}(\lambda)$, given by*:*

$$E_{nmsc} = \int_{250\,nm}^{400\,nm} E_\lambda(\lambda) \cdot s_{nmsc}(\lambda) d\lambda \qquad (5)$$

where

$E_\lambda(\lambda)$ is the spectral irradiance;

$s_{nmsc}(\lambda)$ is the non-melanoma skin cancer weighting function.

3.2.9
Non-melanoma skin cancer radiant exposure
***H*nmsc**

radiant exposure spectrally weighted with the non-melanoma skin cancer weighting function $s_{nmsc}(\lambda)$, given by either :

$$H_{\text{nmsc}} = \int_{250nm}^{400nm} H_\lambda(\lambda) \cdot s_{\text{nmsc}}(\lambda) \mathrm{d}\lambda \qquad (6)$$

or:

$$H_{\text{nmsc}} = \int_{\Delta t_{\text{exp}}} E_{\text{nmsc}}(t) \mathrm{d}t \qquad (7)$$

where

$H_\lambda(\lambda)$ is the spectral radiant exposure;

$s_{nmsc}(\lambda)$ is the non-melanoma skin cancer weighting function;

E_{nmsc} is the non-melanoma skin cancer irradiance.

3.2.10
erythemal effective irradiance
E_{er}

irradiance spectrally weighted with the erythemal weighting function $s_{er}(\lambda)$, given by:

$$E_{er} = \int_{250nm}^{400nm} E_\lambda(\lambda) \cdot s_{er}(\lambda) d\lambda \qquad (8)$$

where

$E_\lambda(\lambda)$ is the spectral irradiance;

$s_{er}(\lambda)$ is the erythemal weighting function.

NOTE The erythemal effective irradiance is defined, from 250 nm to 400 nm, in ISO/CIE 17166.

4 Survey of procedures

There are several procedures which can be applied in order to determine and assess personal UV-radiation exposures caused by the sun:

— Risk assessment using the solar UV-Index (see Clause 5)

— Determination of the skin exposure factor (see Clause 6)

— Calculation of solar radiation exposures depending on geographical parameters (see Clause 7)

— Measurement of the erythemal effective exposure H_{er} (see Clause 8)

— Measurement of the non-melanoma skin cancer radiant exposure H_{nmsc} (see Clause 9)

— Measurement and assessment according to EN 14255-1 (see Clause 10)

NOTE 1 The solar UV-Index is a simple method for prevention purposes. It is normally determined by weather stations or other institutes for a geographic region on a daily basis. It is published via radio, television, newspaper or internet, e.g. in weather forecasts. Hence it can be used by everybody in order to assess the maximum expected regional UV-exposure of the day and to plan appropriate protective measures. The determination of the skin and ocular exposure factors also provides a simple means for everybody to assess the risk caused by solar UV-radiation. The calculation of solar radiation exposures with the aid of computer models can be done when travelling is planned or when a global view of the solar UV-exposure is of interest. These calculations may require a certain skill. Measurements of erythemal effective radiant exposure are done by institutions that possess appropriate technical equipment and skills. They allow the accurate determination of personal UV-exposure. So they can be used for daily prevention purposes but also in research projects. The measurement of the non-melanoma skin cancer radiant exposure will also be carried out by well equipped institutions. It can be used in research projects or when a personal UV-exposure is to be determined in a case of an occupational skin cancer disease. Measurements according to EN 14255-1 also require appropriate technical equipment. UV-exposures of the eyes and the skin are determined accurately. The results can be used for prevention purposes.

Which of the procedures is to be applied in a given situation depends on the context of the solar UV-exposure and should be judged and decided in each specific case. Some of the procedures are quite simple and can be applied by everybody. Other procedures are more refined and accurate but require specialist skills. The advantages and limitations of the procedures are given with their descriptions. This guidance may help to select an appropriate procedure in a specific case.

NOTE 2 There may also be other suitable procedures for the measurement and assessment of UV-exposures of the sun, which are not covered by this standard.

NOTE 3 UV-radiation exposure measurements are often costly and time consuming. This is true especially for solar UV-exposures since the solar spectrum changes during the day and with the seasons. So it may be reasonable to avoid measurements if possible and select a procedure without measurement instead.

5 Risk assessment using the solar UV-Index I_{UV}

5.1 General

Increasing public concern over UV-radiation reaching the earth has brought about the need to communicate daily information to the public in a credible and understandable manner. A unified scale for communicating UV dose rate to the public has been introduced by the World Health Organization (WHO), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Non-Ionizing Radiation Protection Commission (ICNIRP) (see CIE S 013). In the absence of specific information relating to a particular outdoor location, a risk assessment may be made using the solar UV-Index. The solar UV-Index (I_{UV}) is an approximation of the level of erythemally effective ultraviolet radiation which is measured or forecast under the existing or expected weather conditions. Actual values and forecasts are provided by COST [9], weather forecasting services and national radiation protection bodies.

5.2 Determination of solar UV-Index I_{UV}

For the determination of I_{UV} the following procedures are commonly used:

- Earth based continuous measurement of erythemal effective irradiance;
- Calculation of the I_{UV} on earth surface level, taking into account the thickness of the ozone layer, the cloud absorption, albedo, air pollution, etc.;
- Prediction (normally done for one or two days) based upon current measurements, historical information on UV-exposure data and meteorological data [10].

The values of I_{UV} quoted by meteorological organisations are based on the average erythemal effective irradiance during 30 min periods. For forecasts it is most common that the highest I_{UV} expected during a day is presented to the public alongside other weather forecast information. In some cases, the quoted I_{UV} may represent the maximum attainable value if the sky is expected to be cloud free, and in other cases meteorological organisations may choose to present a range of likely I_{UV} values based on the probable accuracy of the weather forecast. The I_{UV} is calculated by meteorological organisations based on knowledge of the spectral content of the sun's ultraviolet emissions, and the effectiveness of the atmosphere in preventing these emissions from reaching the ground. This is a complex procedure, as the terrestrial solar ultraviolet irradiance is affected by solar elevation (which varies predictably with time of year and time of day), ozone layer thickness (historical statistical data may be used to estimate this), air quality (for example, pollutant aerosols), ground reflectance (albedo) and weather (in particular, degree of cloud cover). These data are used by meteorological organisations to calculate the expected solar terrestrial spectral ultraviolet irradiance in a given region on a given day at a given time. The spectral irradiance $E_\lambda(\lambda)$ is weighted with the erythemal weighting function $s_{er}(\lambda)$ and integrated with respect to wavelength (see 3.2.1).

The I_{UV} is normally measured and/or predicted by a few institutions per country, so it is only directly valid for a limited area. When using the I_{UV} for estimating personal exposures the local conditions have to be taken into account.

NOTE 1 For a few specific locations, it is possible to find close-to-live data on the actual I_{UV} measured at that location where the measurements have been carried out [11].

NOTE 2 It should be taken into account that the solar UV-Index is determined for a horizontal plane. A personal UV-exposure on the skin or the eyes may deviate from that because parts of the skin or the eyes may be directed towards or away from the sun.

5.3 Risk assessment

The values of the solar UV-Index range from zero up to 11 in Europe. The higher the index value, the greater the potential for damage to skin and eyes and the less time it takes for harm to occur. WHO recommends a system for the assessment of the risks and personal protection required as listed in Table 2.

Table 2 – Solar UV-Index assessment system (adapted from WHO [3])

Solar Exposure Category	I_{UV} range	Colour Code for Communication	Recommended Protection[1)]
Low	0 to 2	Green	None
Moderate	3 to 5	Yellow	Seek shade during midday hours! Slip on a shirt, slop on sunscreen[2)] and slap on a hat
High	6 to 7	Orange	
Very high	8 to 10	Red	Avoid being outside during midday hours! Make sure you seek shade! Shirt, sunscreen[2)] and hat are a must!
Extreme	11+	Purple	

1) In addition to the personal skin protection required, protection of the eyes should also be taken into account.

2) Sun protection factor (SPF) of sunscreens should be appropriate to the solar exposure category.

NOTE 1 The solar UV-Index has been developed to assess the erythemal risk to the skin. However, in practice it is often also used to estimate other solar UV associated risks like skin cancer, hazards to the eyes, immunosuppression, etc.

NOTE 2 The I_{UV} can also be used to assess the risk of solar UV-exposure for different skin sensitivities and for the eyes (see Table C.1).

5.4 Decision on protective measures

When the solar UV-exposure exceeds a certain level it can be necessary to apply protective measures in order to avoid injuries of the skin and the eyes (see Table 2). A decision on implementation of protective measures may be based on national or international recommendations such as [1]. Examples of such protective measures are given in Annex B.

5.5 Advantages and limitations

Data for the solar UV-Index are readily available e.g. via internet, tv, radio, newspapers and mobile phones. The solar UV-Index is internationally standardised. It is determined by experts and has high accuracy at the locations for which it is determined.

There is a severe limitation to the use of predicted solar UV-Index values as a means of risk assessment. This is that the prediction, based on a forecast of the weather, may be wrong. If the weather is better than was forecast, the solar UV-Index will be higher than forecast. This will be a particular problem if the weather forecast covers a large geographic region.

Unless a range of solar UV-Indexes is forecast, the single figure represents the estimated maximum for the day. On clear days, the solar UV-Index will rise to its maximum value at local solar noon, and then fall again. On such clear days, the solar UV-Index is predictable for different times of the day, and depends only on solar elevation. Note that local solar noon is often not at 12:00 o'clock, but earlier or later.

On cloudy days the maximum solar UV-Index may occur at local solar noon, or it may occur when cloud cover lifts. The behaviour of solar UV-Index on days like this is not predictable. As the solar UV-index is usually determined for a larger regional area, the local solar UV-exposure may deviate due to different cloud cover and other reasons (altitude, albedo, landscape factors). So the local and individual UV-exposure assessment has to be adjusted accordingly.

The solar UV-Index depends on global factors such as geographical position, season, time of day, altitude and cloud cover. It does not directly relate to individual solar UV-exposures, because it does not take into account individual factors such as posture, clothing and time spent outdoors. Due to geometric factors specific sites on the body may receive higher or lower irradiances than indicated by the solar UV-Index, which is defined on a horizontal plane.

6 Determination and assessment of the skin exposure factor

6.1 General

For sun exposures an alternative concept for the hazard evaluation and risk assessment for outdoor workers has been developed [4, 5]. It is based on a set of factors that quantitatively influence the magnitude of skin and eyes exposure in the outdoor environment.

The procedure may be applied to a particular location and to given weather conditions. It takes into regard personal sun protection. So a personal exposure can be estimated. It can be carried out by everybody. No specific equipment or special knowledge is necessary.

The method was originally designed for outdoor workers but can also be applied for the public.

NOTE In this standard the skin exposure factor has been taken from [5]. The ocular exposure factor published in [5] has not been adopted in this European Standard at present due to concerns that its application may not adequately protect the lens from UV-A exposure.

6.2 Skin exposure factor

6.2.1 General

The skin exposure factor f_{SE} is defined in 3.2.2.

6.2.2 Calculation of the skin exposure factor

Depending on the outdoor environment and the personal skin protection, the factors f_1 to f_6 shall be determined according to Table 3. The six factors f_1 to f_6 shall then be multiplied in order to calculate the skin exposure factor f_{SE} (see 3.2.2).

Table 3 — Hazard assessment factors for skin exposure (adapted from [4])

Symbol	Designation	Conditions		Value
f_1	Geographical latitude and season factor	Spring / Summer	> 50° N or S	4
			30° - 50° N or S	7
			< 30° N or S	9
		Autumn / Winter	> 50° N or S	0,3
			30° - 50° N or S	1,5
			< 30° N or S	5
f_2	Cloud cover factor	clear sky		1
		partial cloud sometimes covering sun		0,7
		overcast sky		0,2
f_3	Duration of exposure factor	All day		1
		An hour or two around midday		0,5
		Early morning or late afternoon		0,2
f_4	Ground reflectance factor	Fresh snow		1,8
		Dry sand, sea surf, concrete		1,2
		All other surfaces, including open water		1
f_5	Clothing factor	Unprotected trunk, shoulders & legs		1
		Protected trunk but exposed arms & legs		0,5
		Fully clothed with only hands & face exposed		0,02
f_6	Shade factor	No shade e.g. open fields, tundra, beach, ocean		1
		Partial shade e.g. low density housing, scattered trees		0,3
		Good shade e.g. high density housing, forest, canopy		0,02

6.2.3 Assessment

Depending on the skin exposure factor f_{SE} reference [4] gives guidance which minimal skin protection is recommended (see Table 4).

Table 4 — Skin protection recommendations of [4]

Skin exposure factor	Skin protection required
$f_{SE} < 1$	none
$1 < f_{SE} < 3$	Shirt, brimmed hat
$3 < f_{SE} < 5$	Long-sleeved shirt, trousers, brimmed hat, SPF15+ sunscreen
$f_{SE} > 5$	Modify work environment & practices. Try to create some shade. Long-sleeved shirt and trousers, brimmed hat, SPF15+ sunscreen

Note Detailed information about the skin protection can be found in [2, 3, 12].

6.3 Advantages and limitations

The determination and assessment of the skin exposure factor is a simple means to carry out a rough risk assessment for solar UV-exposures. As it includes information on the individual sun protection a personal UV-exposure can be determined. The individual factors f_1 to f_6 are rough estimations and therefore the resulting skin exposure factor has limited precision. However, the procedure provides a quick and convenient method for hazard assessment and for determining the minimal required protection.

As the solar UV-exposure is estimated and not measured the procedure has a lower accuracy than the measurement methods described in Clauses 8, 9 and 10.

7 Calculation of solar radiation exposures by radiative transfer models

7.1 General

Exposures to UV-radiation emitted by the sun can be calculated by UV forecasting models. Radiative transfer models are used to calculate quantities such as spectral irradiance $E_\lambda(\lambda)$, irradiance $E(\lambda_1$ to $\lambda_2)$ in a defined wavelength band, erythemal effective irradiance E_{er}, ultraviolet hazard irradiance E_s, solar UV-index I_{UV}, etc. on the earth's surface and/or at an altitude above the ground level. Typical input parameters are geographical coordinates such as latitude and longitude, day and time or alternatively the solar zenith angle. Some models also use predicted values of the relevant atmospheric parameters, like ozone, aerosols, etc..

7.2 Models for the calculation of UV-exposure

The available radiative transfer models can be divided into three types:

— Empirical models: Models to compute UV-irradiances based on fits of several years of UV observations. The input variables are usually solar elevation and ozone thickness (Dobson unit). Time duration for the calculation of the result is in the order of milliseconds.

— Fast spectral models: This group covers a wide range of different spectral models. The input variables are ozone thickness, solar elevation and sometimes aerosol concentration. The calculation time is in the order of 0,1 to 10 s.

— Multiple scattering spectral models: In these models the atmosphere is characterized in as much detail as possible (by profiles of temperature, humidity, ozone, sulphur dioxide, aerosols, scattering and absorbing properties of atmospheric constituents, albedo, etc.). The calculation time duration is in the order of 10 to 100 seconds.

A description of several available models is given in [14].

Note A comparison of different calculation models has been carried out in the action “UV-B forecast” within the framework of the European Cooperation in the field of Scientific and Technical research (COST). The results of the comparison have been published [15]. This publication, the results of the comparison and further details are also available in [14]. Further information about activities for the calculation of solar radiation exposures can also be obtained from the website of “COST 713” [9]. COST 713 is an international action dealing with the forecasting of UV-B radiation.

7.3 Assessment of the result

The results of the calculations can be assessed in the same way as the results of the procedures described in Clauses 5, 8 and 10:

— If a value for the solar UV-Index I_{UV} has been calculated the assessment shall be carried out according to 5.3.

— If the erythemal effective radiant exposure H_{er} has been calculated it shall be assessed by using Table A.1. If the erythemal effective radiant exposure H_{er} determined exceeds the minimal erythema dose (*MED*) specified in Table A.1 for the skin type under consideration, erythema may occur when previously unexposed skin is exposed to the sun.

— If the erythemal effective irradiance E_{er} has been determined it can be assessed by using Table 2 after calculating the corresponding UV-Index I_{UV} (see 3.2.1). E_{er} can also be used to calculate the erythemal effective radiant exposure H_{er} and carry out an assessment by using Table A.1. In the latter case H_{er} shall be calculated from E_{er} and the exposure duration Δt_{exp} by using equation (4). Variations of E_{er} during the day shall be taken into account. If the erythemal effective radiant exposure H_{er} determined exceeds the minimal erythema dose (*MED*) specified in Table A.1 for the skin type under consideration, erythema may occur when previously unexposed skin is exposed to the sun.

— If the result of the model calculation is the ultraviolet hazard irradiance E_s the assessment shall be carried out following 10.2.

When carrying out exposure assessments care should be taken on the specifications of the result’s quantities. So e.g. the UV-index I_{UV} is determined by measurements according to 5.2 on a horizontal plane. When it is calculated using a radiative transfer model the reference plane may be different, e.g. perpendicular to the line in which the sun is to be seen. So the result may differ from that obtained by measurements. This difference should be taken into account.

7.4 Necessity of protective measures

If calculation results show a solar UV-radiation exposure at a high level national legislation or international recommendations [1] may require the application of sun protection measures.

7.5 Advantages and limitations of the procedures

Calculations are often carried out easily and rapidly. There are internet-websites which provide such calculations. The input data are sometimes just the geographical coordinates, time and day. When weather conditions are also regarded in the model, the results should be reasonably accurate. Advantages and limitations are similar to those described in 5.5. So e.g. the prediction is made for an area and does not directly relate to a personal exposure. In any case the user should know how the calculation is done in order to recognize sources of inaccuracies.

8 Measurement of erythemal effective radiant exposure H_{er}

8.1 General

Compared to the previously described methods (estimation using UV-Index, calculation using the exposure factor model or computer aided methods) measurements of personal solar UV-exposure are complex and costly. They can, however, provide very precise information about solar UV-exposure. Usually such measurements are used for scientific research (e.g. for different population/behaviour groups, different professions, input data for new models, validation of existing models [21]) or for survey measurements in outdoor work situations where precise determination is needed and estimations are inadequate. Also when investigating suspected cases of photo-related diseases, personal solar UV-exposure measurements can be necessary as an additional diagnostic method.

8.2 Quantities to be measured

The radiometric quantity to be determined is the erythemal effective radiant exposure H_{er} of solar radiation measured at the body surface of the exposed person. The personal erythemal effective UV-exposure can be obtained:

- directly
  by measuring the erythemal effective radiant exposure H_{er} with a personal worn detector (dosemeter). This method is preferred as it allows the most accurate skin exposure determination at different body sites on a moving person [16].

- indirectly
  by measuring the erythemal effective irradiance E_{er} using a static detector and determining the exposure duration Δt_{exp}.

- indirectly
  by measuring the spectral irradiance $E_{\lambda}(\lambda)$ using a static detector, weighting the result with the erythemal weighting function s_{er} and determining the exposure duration Δt_{exp}

- indirectly
  by measuring the erythemal effective radiant exposure H_{er} using a static detector.

8.3 Description of the methods

Measurements of the erythemal effective radiant exposure H_{er} can have different aims:

- determination of the solar exposure distribution on the body
  This is best done by using personal dosemeters worn at several sites on the body, typically during long periods.

- determination of the worst case exposure as part of a risk assessment
  This is best done by using static detectors which are oriented towards the sun, typically during short term periods when highest intensity is expected. For the assessment of the measurement result Table A.1 can be used. If the erythemal effective radiant exposure H_{er} determined exceeds the minimal erythema dose (*MED*) specified in Table A.1 for the skin type under consideration, erythema may occur when previously unexposed skin is exposed to the sun.

- determination of the exposure under open shadow conditions as part of a risk assessment
  This is best done by using static detectors, shaded from the direct sun, oriented towards the open sky typically during short term periods when highest intensity is expected. It represents typical situations where persons are exposed to scattered radiation, but are shaded from the direct sun. For the assessment of the measurement result Table A.1 can be used. If the erythemal effective radiant exposure H_{er} determined exceeds the minimal erythema dose (*MED*) specified in Table A.1 for the skin type under consideration, erythema may occur when previously unexposed skin is exposed to the sun.

- determination of the global (ambient) irradiance on a horizontal plane
  This is done by using static detectors on a horizontal plane typically during a day. The measurements may be repeated on several days. The results can be used for estimations of:

  - the distribution of personal exposures across the body using models [16, 17, 21]

  - the daily and/or annual solar exposures of different occupation groups [16, 21]

Methods for measuring H_{er} are described in Annex D. Their suitability for different measurement aims is indicated in Table 5.

Table 5 — Suitable methods for determination of the erythemal effective radiant exposure H_{er} depending on the measurement aim (see Annex D)

Measurement aim	Suitable methods					
	A	B	C	D	E	F
determination of the solar exposure distribution on the body	X	X				
determination of the worst case exposure as part of a risk assessment			X	X	X	X
determination of the exposure under open shadow conditions as part of a risk assessment			X	X	X	X
determination of the global (ambient) irradiance on a horizontal plane			X	X	X	
X = suitable						

NOTE In principle, the methodology as described in EN 14255-1 can also be used. There are, however, some differences:

— In EN 14255-1 risk assessment is based upon the ICNIRP combined spectral weighting function $s(\lambda)$ for eyes and skin (ultraviolet hazard radiant exposure), whereas the erythemal effective radiant exposure H_{er} is related to the CIE S007 erythemal weighting function $s_{er}(\lambda)$.

— Apart from spectral weighting function choice, the suitability of the methods described in EN 14255-1 is restricted by several specifics of the spectral distribution of the solar UV-radiation on earth such as:

  — The variation of spectral irradiance $E_\lambda(\lambda)$ (> 10^5) in the wavelength range 280 nm to 400 nm, and the large amount of visible and IR radiation in solar radiation, require measurement devices with a very good straylight suppression.

  — The distribution of spectral irradiance $E_\lambda(\lambda)$ varies in the course of a day and furthermore in the course of a year. Therefore the spectral sensitivity has to accurately match the erythemal weighting function $s_{er}(\lambda)$ in systems using broadband sensors.

8.4 Advantages and limitations

The measurement of H_{er} allows the determination of the personal UV-exposure. It can be used to determine the personal UV-exposure as a basis for a risk assessment and the application of protective measures. As measurements are costly and time consuming they will presumably seldom be performed for this purpose. But it can also be used in research projects where the connection between UV-exposure and erythema induction is to be investigated.

The measurement of H_{er} cannot be used to assess the risk of UV-induced injuries to the eyes.

9 Measurement of non-melanoma skin cancer radiant exposure H_{nmsc}

9.1 General

UV-radiation exposure is the major factor contributing to the risk of getting non-melanoma skin cancer. The personal non-melanoma skin cancer radiant exposure H_{nmsc} may be measured as part of a skin cancer risk assessment. This may be done in scientific research projects when the connection between UV-exposure and skin cancer induction is to be investigated. It may also be done when past personal UV-exposures are to be determined in a case of an occupational skin cancer disease. Non-melanoma skin cancer includes basal cell carcinoma and squamous cell carcinoma, but does not include malignant melanomas. An action spectrum for non-melanoma skin cancer is provided by CIE (see CIE S 019). Risk assessments using dose-response relationships are currently under scientific investigation. Skin cancer does not occur immediately after the UV-exposure but with a delay of years or even decades. However preliminary signs of skin aggravation can be recognized before clinical manifestation of skin cancer.

9.2 Procedure

In principle, the methods described in EN 14255-1:2005, 7.3 and Annex D, are also applicable for the measurement of the non-melanoma skin cancer radiant exposure H_{nmsc} according to the definition in 3.2.9. Irradiance spectrally weighted with the non-melanoma skin cancer weighting function $s_{nmsc}(\lambda)$ is to be determined. In order to do this the spectral irradiance $E_{\lambda}(\lambda)$ can be measured and the non-melanoma skin cancer irradiance E_{nmsc} can then be calculated by using the non-melanoma skin cancer weighting function $s_{nmsc}(\lambda)$ (see 3.2.8). Or the non-melanoma skin cancer irradiance E_{nmsc} can directly be measured by an instrument which internally makes the spectral weighting according to $s_{nmsc}(\lambda)$ (e.g. by an appropriate filter). In addition to measuring E_{nmsc} the exposure duration Δt_{exp} is to be measured, too. The non-melanoma skin cancer radiant exposure H_{nmsc} is then calculated using equation (7). Alternatively an instrument can be used which measures the non-melanoma skin cancer radiant exposure H_{nmsc} directly, e.g. a dosemeter with built-in $s_{nmsc}(\lambda)$ weighting function.

As a personal UV-exposure is to be determined, it should carefully be taken into consideration if a static measurement device can be used or if one or more personal dosemeters should be affixed to the person.

9.3 Protective measures

Currently there are no limit values set or recommended using the quantity non-melanoma skin cancer radiant exposure. Nevertheless, the risk of skin cancer induction increases if the skin is either chronically or acutely overexposed to UV-radiation. Therefore it is reasonable to apply appropriate protective measures in order to avoid skin cancer (see Annex B). According to recommendations by WHO [1] and ICNIRP [18] an appropriate sun protection against erythema also protects against skin cancer.

9.4 Advantages and limitations

The procedure allows the determination of skin cancer related UV-exposure. It can be used in research projects when the connection between UV-exposure and skin cancer induction is to be investigated. It can also be used when a past personal UV-exposure is to be determined in a case of an occupational skin cancer disease.

The procedure cannot be used to assess the risk of acute UV-induced injuries such as skin erythema.

10 Measurement and assessment according to EN 14255-1

10.1 General

In principle personal UV-radiation exposures caused by the sun can be determined and assessed in a similar way to that specified in EN 14255-1. This means that the quantities such as H_s(UV-A/B/C) and H(UV-A) are determined and the results are compared with recommended limit values.

NOTE If solar UV irradiance is insignificant or extreme, a precise assessment may be unnecessary. In cases where it cannot readily be foreseen whether limit values are exceeded or not, measurements according to EN 14255-1 can be valuable.

The methods described in EN 14255-1 can be applied to solar UV-exposures, e.g. if the sun is near the horizon or if the sky is cloudy. In these cases the radiation level might be near to the limit values and within the measurement range of commonly used UV-measurement procedures (see Annexes C and D of EN 14255-1:2005).

10.2 Procedure

The main steps of the procedure are:

— Measurement of the relevant radiometric quantities according to 7.2 of EN 14255-1:2005. E.g. if the limit value recommendations of the International Commission on Non-Ionizing Radiation (ICNIRP) [18] are used, the quantities to be determined are the ultraviolet hazard radiant exposure H_s for λ = 180 nm to 400 nm and the radiant exposure H for λ = 315 nm to 400 nm.

— Assessment of the UV-exposure by comparison of the measured values with required or recommended limit values, e. g. the ICNIRP limit value recommendations [18].

Defining the direction of measurement is also important. When the sun is at high elevations and the sky is clear the eyes are normally not directed to the sun, but to the earth or to the background of the sky. The skin may nevertheless be directly exposed by the sun in this situation. When the sun elevation is low or the sky is cloudy it can happen that the eyes (as well as the skin) are directed at the sun. So during a measurement according to EN 14255-1 a decision shall be made, depending on the specific situation, whether the measurement should be done in the direction of the sun or whether the direction of the sun should be left out.

10.3 Protective measures

If the applied UV-exposure limit values are exceeded national legislation or international recommendations may require the application of protective measures (see 11).

10.4 Advantages and limitations

The procedure provides a means for the precise determination of the personal UV-exposure. It takes into account both the exposure of the eyes and the exposure of the skin. Exposure limit value recommendations are available [18], so the personal UV-exposure determined can easily and accurately be assessed. Therefore the method is suitable for prevention purposes.

Limitations of the application of the procedure are:

— Clear sky and high sun elevation leads to very high UV- and visible radiation exposures. This may cause problems with measurements, as the upper threshold of the measurement range of most of the UV-measurement procedures will be exceeded.

— The solar spectrum tends to show high irradiance values within the visible and IR-range versus relatively low irradiance values within the UV range. For broadband UV-radiometers intended for application in sunlight, an excellent discrimination of visible light and infrared radiation is needed. So called solar-blind detectors (e.g. SiC) are beneficial.

— Compared to UV-A, the amount of UV-B that reaches the earth's surface varies more strongly with factors such as air pollution. This means that broadband radiometers that directly display a biologically weighted value should very closely match the pertaining action spectrum.

— Measurements according to EN 14255-1 can be carried out in order to reflect the exposure situation of a person staying outdoors with relatively low sun exposure (e. g. low sun elevation or overcast sky). In these situations skin and eyes may be exposed to direct sun radiation and methods according to EN 14255-1 are applicable. In exposure situations with high solar irradiation (e. g. high sun elevation at noon) people avoid exposing the eyes directly to the sun. In these cases measurements according to EN 14255-1 are inappropriate.

11 Sun protection measures

If the solar UV-exposure determined and assessed is on such a high level that injuries of the skin or the eyes may occur, international guidelines recommend the application of sun protection measures [3, 18]. Which protection measures are to be applied is outside the scope of this European Standard. National legislation may require the application of sun protection measures. Examples of protective measures recommended by different organizations are given in Annex B.

Annex A
(normative)

Relation between skin type and minimal erythema dose

Table A.1 — Relation between skin type and minimal erythema dose

Skin type	**Skin classification**	**Sunburn/tanning history**	**Minimal erythema dose (*MED*) range,** expressed in SED
I	Melano - compromised	Always burns easily, never tans	1,5 to 3,0
II		Always burns easily, tans minimally	2,5 to 3,5
III	Melano - competent	Burns moderately, tans gradually (light brown)	3,0 to 5,0
IV		Burns minimally, tans well always (moderate brown)	4,5 to 6,0
V	Melano - protected	Rarely burns, tans profusely (dark brown)	6,0 to 10
VI		Never burns, deeply pigmented (black)	10 to 20

NOTE The values listed for minimal erythema dose range are only valid for unadapted skin.

Annex B
(informative)

Examples of protective measures

Avoidance of exposure

— If feasible, avoidance of staying outdoors around solar noon

Technical measures

— Providing shade

Organizational measures

— Planning outdoor activities in such a way that people move along with the shadow

— Instruction of persons in the hazards of ultraviolet radiation and in the use of suitable protective measures

Personal protective measures and equipment

— Suitable sunglasses for the protection of the eyes and especially in situations with high albedo (e.g. snow, sand, water, large concrete areas, etc.)

— Suitable headwear (e.g. a broad-brimmed hat)

— Suitable clothing (e.g. long sleeves for the protection of the skin)

— Application of sunscreen with an appropriate protection factor, if feasible

Annex C
(informative)

UV skin and eye risks

The risks for skin and eyes are given on a scale from 0 to 10 with: 0 no risk, 10 maximum risk.

Table C.1 — Skin and eye risks related to solar UV-Index [19]

Solar UV-exposure category (based on solar UV-Index I_{uv})	**Skin risk**			**Eye risk**
	Melano-compromised	**Melano-competent**	**Melano-protected**	
Low: I_{uv} 0 to 2	0	0	0	0
Moderate: I_{uv} 3 to 5	1	0	0	1
High: I_{uv} 6 to 7	3	1	0	3
Very high: I_{uv} 8 to 10	6	3	1	6
Extreme: I_{uv} 11+	10	6	3	10

Annex D
(informative)

Methods for the measurement of solar erythemal effective radiant exposure H_{er}

D.1 General

Measurements of the erythemal effective radiant exposure H_{er}, for an estimation of solar UV-exposures, can be carried out either by wearing personal dosemeters (direct methods) or by using static detectors (indirect methods).

Subsequently different methods for the measurement of exposures to ultraviolet radiation emitted by the sun are listed. The methods are determined by the

- quantity or quantities to be measured;
- measurement devices used;
- way of performing the measurement (personally worn or static detector);
- measurement time and duration;
- calculation of the result from the measured quantity or quantities.

Tables in Annex D are not intended to be exhaustive.

D.2 Methods A to F for the measurement of the erythemal effective radiant exposure H_{er}

D.2.1 General

Measurements of the erythemal effective radiant exposure H_{er} can have different aims:

- determination of the solar exposure distribution on the body
  personal dosemeters are suitable for this task (see methods A and B)
- determination of the worst case exposure
  static detectors oriented towards the sun are suitable for this task (see methods C, D, E, F)
- determination of the exposure under open shadow conditions
  static detectors shaded from the direct sun, oriented towards the open sky are suitable for this task (see methods C, D, E, F)
- determination of the global (ambient) irradiance on a horizontal plane
  static detectors on a horizontal plane are suitable for this task (see methods C, D, E).

Depending on the aim, the erythemal effective radiant exposure H_{er} can be determined by using one of the methods A to F.

D.2.2 Method A

Measurement using a personal active dosemeter which is calibrated to measure the erythemal effective radiant exposure H_{er}.

The spectral sensitivity of the dosemeter has to match the erythemal weighting function $s_{er}(\lambda)$. The erythemal effective radiant exposure H_{er} has to be measured throughout the exposure duration Δt_{exp}. In order to determine H_{er} for different parts of the body, it is useful to distribute several dosemeters across the body.

NOTE 1 This method is particularly suitable for work task analysis.

NOTE 2 Active dosemeters have electronic sensors incorporated. The results can be stored in a data logger, thus providing time resolved data for later analysis.

Table D.1 — Advantages and disadvantages of method A

Advantages	Disadvantages
• Representative measurement of personal erythemal effective radiant exposure H_{er} • Simple performance of measurement • Additional time measurement not necessary • Time-resolved storage of the exposure data • Exposure distribution across the body determinable • Reusable personal dosemeter	• In cases of insufficient matching the erythemal weighting function $s_{er}(\lambda)$, the measurement uncertainty may be large • Systems of sufficient accuracy are relatively expensive • Determination of exposure distribution across the body requires several devices

D.2.3 Method B

Measurement using a personal passive dosemeter which is calibrated to measure the erythemal effective radiant exposure H_{er}.

The spectral sensitivity of the dosemeter has to match the erythemal weighting function $s_{er}(\lambda)$. The erythemal effective radiant exposure H_{er} has to be measured throughout the exposure duration Δt_{exp}. In order to determine H_{er} for different parts of the body, it is useful to distribute several dosemeters across the body.

NOTE 1 This method is particularly suitable for work task analysis.

NOTE 2 Passive dosemeters use photochemical or photobiological sensors. They provide cumulative data. Additional equipment is required for the analysis.

Table D.2 — Advantages and disadvantages of method B

Advantages	Disadvantages
• Representative measurement of personal erythemal effective radiant exposure H_{er} • Simple performance of data collection • Additional time measurement not necessary • Exposure distribution across the body determinable	• In cases of insufficient matching the erythemal weighting function $s_{er}(\lambda)$, the measurement uncertainty may be large • Additional equipment needed for the analysis • Offline analysis introduces time delay • Single use personal dosemeter. Therefore expensive if repeated measurements are needed.

D.2.4 Method C

a) Measurement using a static broad-band radiometer which is calibrated to measure the erythemal effective irradiance E_{er}. The spectral sensitivity of the radiometer has to match the erythemal weighting function $s_{er}(\lambda)$.

b) Measurement and documentation of the time of solar exposure duration Δt_{exp}.

c) Calculation of the erythemal effective radiant exposure H_{er} by using equation (4).

Table D.3 — Advantages and disadvantages of method C

Advantages	Disadvantages
• Direct reading of erythemal effective irradiance E_{er} • Rapid measurements (typically in the order of ms) • Relatively inexpensive • Flexible use (portable, compact, maybe battery powered, easy handling)	• Only static measurements without individual characterisation either of exposures at different body sites or of the moving person • Additional exposure duration measurement(s) necessary. Its accuracy may be poor. • In cases of insufficient matching the erythemal weighting function $s_{er}(\lambda)$, the measurement uncertainty can be large

D.2.5 Method D

a) Measurement of the spectral irradiance $E_\lambda(\lambda)$ in the wavelength-range from 280 nm to 400 nm using a static array spectroradiometer.

b) Measurement and documentation of the time of solar exposure duration Δt_{exp}.

c) Calculation of the erythemal effective radiant exposure H_{er} by using equation (3).

Table D.4 — Advantages and disadvantages of method D

Advantages	Disadvantages
• In comparison to scanning spectroradiometers fast measurement reduces risk of errors due to short term variation of solar irradiance • Compact systems are available • High radiometric accuracy is possible • Solar spectral information is obtained instantly	• Only static measurements without individual characterisation either of exposures at different body sites or of the moving person • Additional exposure duration measurement(s) necessary. Its accuracy may be poor. • Systems of sufficient accuracy are likely to be expensive

D.2.6 Method E

a) Measurement of the spectral irradiance $E_\lambda(\lambda)$ in the wavelength-range from 280 nm to 400 nm using a static scanning spectroradiometer

b) Measurement and documentation of the time of solar exposure duration Δt_{exp}

c) Calculation of the erythemal effective radiant exposure H_{er} by using equation (3).

Table D.5 — Advantages and disadvantages of method E

Advantages	Disadvantages
• Accurate measurement of spectral irradiance $E_\lambda(\lambda)$ of time constant radiation intensities • High radiometric accuracy is possible • Solar spectral information is obtained	• Only static measurements without individual characterisation either of exposures at different body sites or of the moving person • Additional exposure duration measurement(s) necessary. Its accuracy may be poor. • In comparison to array spectroradiometers slow measurement increases the risk of errors due to short term variation of solar irradiance • Systems of sufficient accuracy are likely to be expensive and bulky.

D.2.7 Method F

Measurement using a static broad-band radiometer which is calibrated to measure the erythemal effective radiant exposure H_{er}.

The spectral sensitivity of the radiometer has to match the erythemal weighting function $s_{er}(\lambda)$.The erythemal effective radiant exposure H_{er} has to be measured throughout the exposure duration Δt_{exp} according to the aim of the measurement.

Table D.6 — Advantages and disadvantages of method F

Advantages	Disadvantages
• Direct reading of erythemal effective radiant exposure H_{er} • Relatively inexpensive • Flexible use (portable, compact, maybe battery powered, easy handling)	• Only static measurements without individual characterisation either of exposures at different body sites or of the moving person • In cases of insufficient matching the erythemal weighting function $s_{er}(\lambda)$, the measurement uncertainty can be large

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