Measurement and assessment of personal exposures to incoherent optical radiation —

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

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Messung und Beurteilung von personenbezogenen Expositionen gegenüber inkohärenter optischer Strahlung - Teil 4: Terminologie und Größen für Messungen von UV-, sichtbaren und IR-Strahlungs-Expositionen

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Foreword

This document (EN 14255-4:2006) 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of an identical text or by endorsement, at the latest by April 2007, and conflicting national standards shall be withdrawn at the latest by April 2007.

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: UV-Radiation emitted by the sun (in preparation)

Part 4 (this part): Terminology and quantities used in UV-, visible and IR-exposure measurements

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Introduction

People may be exposed to adversely high levels of optical radiation (ultraviolet, visible and infrared radiation) from strong optical radiation sources in the workplace and elsewhere. In order to protect people from harm their optical radiation exposures should be determined in these cases and compared with limit values which are set by national authorities or recommended by international organisations (e.g. ICNIRP[1)], see [5], [6], [7], [8], [11]). Part 1 of this standard describes methods to determine ultraviolet (UV) radiation exposures in the workplace, part 2 of this standard describes methods to determine visible (VIS) and infrared (IR) radiation exposures in the workplace and part 3 of this standard describes methods to determine ultraviolet radiation exposures by the sun.

There are several quantities in which optical radiation exposures are expressed. Unfortunately some of these quantities are defined and named in different ways by different reference sources, such as standards and limit value recommendations. Additionally, some of the quantities are not always very well defined in a strong physical and mathematical sense. Hence there is a need for clarification and uniform definition of these quantities.

In this part 4 of the standard a uniform terminology for quantities is specified and the quantities are defined in a way which makes them reasonably applicable in practical use. The terminology and quantities defined may be used when parts 1, 2 and 3 of this standard are applied or when relevant standards or limit value recommendations are to be revised.

In this standard, terms which are often expressed elsewhere as summations have been reformulated and expressed mathematically as integrals. Cumbersome terms in current use, such as time integrated radiance, have been replaced by newly defined terms which clarify the relationship between, for example, radiance and radiance dose.

In order to specify and define quantities more clearly, some of the quantities have been renamed. In this standard the names of these quantities differ from the names used in other reference sources. The reason is that within the referred sources the names of these quantities are not sufficiently descriptive, e.g. "effective irradiance E_{eff}" and "effective radiant exposure H_{eff}" are very general expressions (see CIE[2)] 17.4) but are used in some references in very specific meanings. In the definition of ICNIRP [5] "effective irradiance" is a quantity which describes the effect of UV radiation as well on the skin as on the eyes. So the quantity is mainly used for prevention purposes when it is often not known which part of the body will be exposed. So this useful quantity has a very specific meaning and it is named in this standard with the specific name "ultraviolet hazard irradiance E_s".

Another reason for renaming the quantity "effective irradiance" is that it is used in some applications to indicate a net effect such as the difference between incident and emitted heat radiation. In order to avoid misunderstandings the term "effective irradiance" is not used in this standard. The more specific term "ultraviolet hazard irradiance" is used instead.

NOTE Terms and quantities which are not covered by this part of the standard can be found in other reference sources like CIE 17.4, CIE S 007 or CIE S 009.

1) ICNIRP International Commission on Non-Ionizing Radiation Protection.

2) CIE Commission Internationale de l'Éclairage.

1 Scope

This standard specifies the terminology and the quantities that are used in UV-, VIS- and IR-exposure measurements according to parts 1, 2 and 3 of EN 14255.

NOTE Parts 1 and 2 were published in 2005, while part 3 is under preparation.

This standard can also be applied to the terminology and quantities used in international recommendations from, e.g. ICNIRP, CIE, etc. The purpose of this standard is to unify the definitions of quantities for optical radiation measurements since inconsistencies occur between existing publications from different origins.

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.

Not applicable.

3 Terms and definitions

3.1 Symbols, terms and units

Within the field of applications of parts 1, 2 and 3 of EN 14255 the symbols, terms and units listed in Table 1 are used.

Table 1 —Symbols, terms and units

Symbol	Term	Unit	Defined in
λ	wavelength	nm	CIE 17.4:1987 ref 845-01-14
λ_1 , λ_2	boundaries of a wavelength-range $\Delta\lambda$	nm	EN 14255-4
$\Delta\ t_{exp}$,	exposure duration	s	EN 14255-4
E	irradiance	W/m²	CIE 17.4:1987 ref 845-01-37
$E_\lambda(\lambda,t)$, $E_\lambda(\lambda)$	spectral irradiance	W/(m² × nm)	EN 14255-4
H	radiant exposure	J/m²	CIE 17.4:1987 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
E_b	blue-light irradiance	W/m²	EN 14255-4
H_b	blue-light radiant exposure	J/m²	EN 14255-4
L	radiance	W/(m² × sr)	CIE 17.4:1987 ref 845-01-34 and CIE S 009/E:2002 clause 3.31
$L_\lambda(\lambda)$	spectral radiance	W/(m² × nm × sr)	CIE S 009/E:2002 clause 3.41
L_b	blue-light radiance	W/(m² × sr)	EN 14255-4
L_r	retinal thermal radiance	W/(m² × sr)	EN 14255-4
G	radiance dose	J/(m² × sr)	EN 14255-4
G_b	blue-light radiance dose	J/(m² × sr)	EN 14255-4
—	spectral weighting function	—	EN 14255-4
$s(\lambda)$	ultraviolet hazard weighting function	—	EN 14255-4
$b(\lambda)$	blue light hazard weighting function	—	EN 14255-4
$r(\lambda)$	retinal thermal hazard weighting function	—	EN 14255-4
D	source diameter	m	EN 14255-4
D_L	viewing source diameter	m	EN 14255-4
D_{app}	apparent source diameter	m	EN 14255-4
r	viewing distance	m	EN 14255-4
ϕ	viewing angle	rad	EN 14255-4
γ	angle of acceptance	rad	EN 14255-4

Table 1 (continued)

Symbol	Term	Unit	Defined in
α	angular subtense of the apparent source	rad	CIE S009/E:2002 clause 3.2
I_{UV}	UV-Index	—	CIE S 013/E
f_{OE}	ocular exposure factor	—	ILO/ICNIRP Guide
f_{SE}	skin exposure factor	—	ILO/ICNIRP Guide
$s_{er}(\lambda)$	erythemal weighting function	—	ISO/CIE 17166 and EN 14255-4
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	100 J/m²	ISO/CIE 17166
MED	minimal erythema dose	J/m² or SED	ISO/CIE 17166
$s_{nmsc}(\lambda)$	non-melanoma skin cancer weighting function	—	CIE DS 019.2/E
E_{nmsc}	non-melanoma skin cancer effective irradiance	W/m²	EN 14255-4
H_{nmsc}	non-melanoma skin cancer effective radiant exposure	J/m²	EN 14255-4
NOTE Angles like angular subtense α, viewing angle ϕ and angle of acceptance γ are often expressed in degrees instead of radians.			

3.2 Definitions

NOTE Quantities for the irradiance, radiance and radiant exposure, which are calculated by using spectral weighting functions, are named in reference to the specific action spectrum in question. For any specific effect "x", if a spectral weighting function x(λ) exists, the "x-irradiance E_x" can be calculated equivalent to equation (4); e. g. the name "blue-light irradiance E_b" is used for the wavelength integral of the spectral irradiance which is spectrally weighted with the blue-light hazard weighting function $b(\lambda)$. The blue-light hazard weighting function $b(\lambda)$ is related to the action spectrum of the blue-light hazard of the eye. Likewise, other names of quantities which allow the assessment of a specific effect are chosen in relation to the action spectra in question. The same procedure may be applied for other spectrally weighted quantities such as radiant exposure H_x, radiance L_x, etc.

3.2.1
boundaries of a wavelength-range

λ_1, λ_2

lower and upper wavelength value specifying the boundaries for a wavelength-range of interest

NOTE Wavelength-ranges are used to specify the spectral boundaries for weighting functions (for hazards or beneficial effects), measurement device specifications, source emission spectra, etc. When applying exposure limit values the wavelength range of interest will depend on the biological effect under consideration.

3.2.2
exposure duration
Δt_{exp},
time interval between the beginning and the end of an optical radiation exposure

NOTE Exposure duration can refer to a single discrete exposure, the sum of several exposure periods in a series of intermittent exposures, or the total time period from the beginning to the end of a series of intermittent exposures.

3.2.3
spectral irradiance
$E_\lambda(\lambda,t)$, $E_\lambda(\lambda)$
differential quotient of the irradiance, $E(\lambda,t)$ with respect to the wavelength λ, given by either:

$$E_\lambda(\lambda,t) = \frac{\partial E(\lambda,t)}{\partial \lambda} \quad (1)$$

or

$$E_\lambda(\lambda) = \frac{\partial E(\lambda)}{\partial \lambda} \quad (2)$$

NOTE 1 E_λ and $E_\lambda(\lambda)$ are used similarly in other sources (e.g. ICNIRP [5], CIE S 009, IEC TR 60825-9).

NOTE 2 If the spectral irradiance is not time dependent, equation 2 applies.

3.2.4
spectral radiant exposure
$H_\lambda(\lambda)$
time integral of the spectral irradiance, $E_\lambda(\lambda,t)$ during the exposure duration Δt_{exp}, given by:

$$H_\lambda(\lambda) = \int_{\Delta t_{exp}} E_\lambda(\lambda,t)\,\mathrm{d}t \quad (3)$$

3.2.5
ultraviolet hazard irradiance
E_s
irradiance spectrally weighted with the ultraviolet hazard weighting function $s(\lambda)$, given by:

$$E_\mathrm{s} = \int_{\lambda_1}^{\lambda_2} E_\lambda(\lambda) s(\lambda)\,\mathrm{d}\lambda \quad (4)$$

3.2.6
ultraviolet hazard radiant exposure
H_s
radiant exposure spectrally weighted with the ultraviolet hazard weighting function $s(\lambda)$, given by either:

$$H_\mathrm{s} = \int_{\lambda_1}^{\lambda_2} H_\lambda(\lambda) s(\lambda)\,\mathrm{d}\lambda \quad (5)$$

or

$$H_\mathrm{s} = \int_{\Delta t_{exp}} E_s(\mathrm{t})\,\mathrm{d}t \quad (6)$$

NOTE If $s(\lambda)$ is chosen to correspond to the ICNIRP relative spectral effectiveness $S(\lambda)$ [5, 7], the ultraviolet hazard radiant exposure H_s will correspond to the ICNIRP effective radiant exposure H_{eff} .

3.2.7
blue-light irradiance
E_b
irradiance spectrally weighted with the blue-light hazard weighting function *b(λ)*, given by:

$$E_b = \int_{\lambda_1}^{\lambda_2} E_\lambda(\lambda) b(\lambda) \mathrm{d}\lambda \tag{7}$$

3.2.8
blue-light radiant exposure
H_b
radiant exposure spectrally weighted with the blue-light hazard weighting function *b(λ),* given by either:

$$H_b = \int_{\lambda_1}^{\lambda_2} H_\lambda(\lambda) b(\lambda) \mathrm{d}\lambda \tag{8}$$

or

$$H_b = \int_{\Delta t_{\mathrm{exp}}} E_b(\mathrm{t}) \mathrm{d}t \tag{9}$$

3.2.9
blue-light radiance
L_b
radiance spectrally weighted with the blue-light hazard weighting function *b(λ)*, given by:

$$L_b = \int_{\lambda_1}^{\lambda_2} L_\lambda(\lambda) b(\lambda) \mathrm{d}\lambda \tag{10}$$

3.2.10
retinal thermal radiance
L_r
radiance spectrally weighted with the retinal thermal hazard weighting function *r(λ),* given by:

$$L_r = \int_{\lambda_1}^{\lambda_2} L_\lambda(\lambda)\, r(\lambda) \mathrm{d}\lambda \tag{11}$$

3.2.11
radiance dose
G
time integral of the radiance, $L(t)$ during the exposure duration Δt_{exp}, given by:

$$G = \int_{\Delta t_{\mathrm{exp}}} L(t) \mathrm{d}t \tag{12}$$

3.2.12
blue-light radiance dose
G_b
time integral of the blue-light radiance $L_b(t)$ during the exposure duration Δt_{exp}, given by:

$$G_b = \int_{\Delta t_{\mathrm{exp}}} L_b(t) \mathrm{d}t \tag{13}$$

3.2.13
spectral weighting function
wavelength dependent mathematical function used to calculate a quantity for assessing the potential effect of an optical radiation exposure

NOTE 1 For exposure assessment purposes, a weighting function is derived from an action spectrum which represents the relationship between a physical quantity and a particular biological effect resulting from exposure to optical radiation. It reflects the relative spectral efficacy of the radiation in causing the effect. It is a dimensionless wavelength dependent function.

NOTE 2 A biological action spectrum represents the wavelength dependency of a particular biological effect (see CIE 17.4 and CIE 106).

3.2.14
ultraviolet hazard weighting function
$s(\lambda)$
spectral weighting function intended for health protection purposes and reflecting the combined acute effects of ultraviolet radiation on the eye and the skin

NOTE Values for this function are specified, e.g. by ICNIRP [5,6,11] within a wavelength range from 180 nm to 400 nm. ICNIRP uses a different symbol, namely *"S_λ"* and also a different name: "Relative spectral effectiveness".

3.2.15
blue-light hazard weighting function
$b(\lambda)$
spectral weighting function reflecting the photochemical effects of ultraviolet and visible radiation on the retina

NOTE Values for this function are specified, e.g. by ICNIRP [8] within a wavelength range from 300 nm to 700 nm. ICNIRP uses a different symbol, namely *"$B(\lambda)$"* and also a slightly different name: "Blue-light hazard function".

3.2.16
retinal thermal hazard weighting function
$r(\lambda)$
spectral weighting function reflecting the thermal effects of visible and near-infrared radiation on the retina

NOTE Values for this function are specified, e.g. by ICNIRP [8] within a wavelength range from 380 nm to 1400 nm. ICNIRP uses a different symbol, namely *"$R(\lambda)$"* and also a slightly different name: "Retinal thermal hazard function".

3.2.17
erythemal weighting function
$s_{er}(\lambda)$
spectral weighting function reflecting the erythemal effect of ultraviolet radiation on the skin

NOTE This 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.

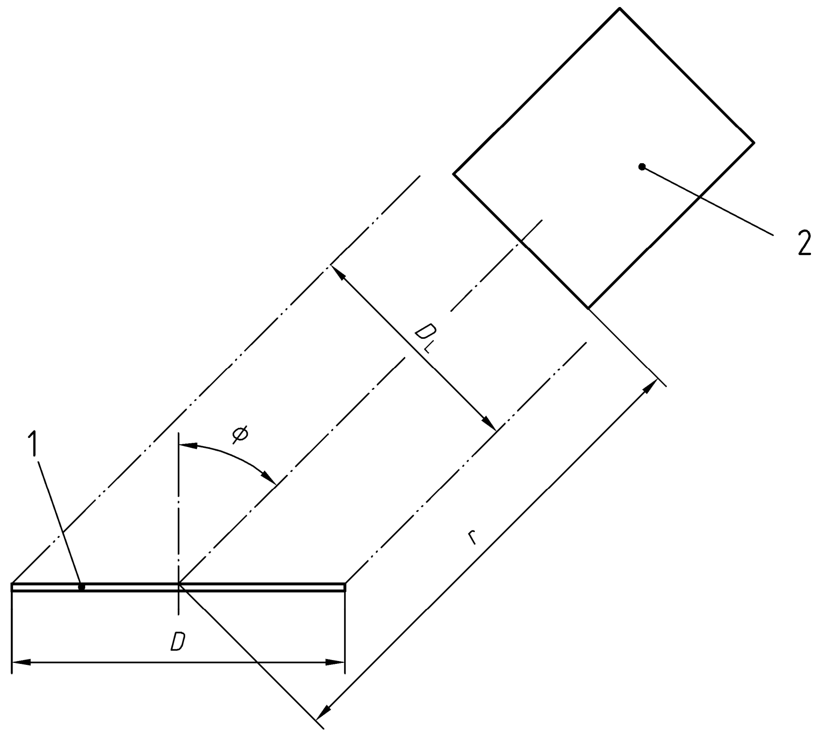
3.2.18
source diameter
D
diameter of the circle, if the source is circular,

or

arithmetic mean of the longest and shortest geometric dimension, if the source is oblong

3.2.19
viewing source diameter
D_L
diameter of the source as seen from the point of observation (see Figure 1), given by:

$$D_L = D \cos \phi \quad (14)$$



Key

1 radiation source

2 detector

Figure 1 — Connection between the source diameter *D*, viewing source diameter D_L and viewing angle ϕ

3.2.20
apparent source diameter
D_{app}
virtual diameter of a source as apparent at the point of observation, if the radiation geometry is affected by optical elements

NOTE The apparent source diameter replaces the viewing source diameter (equation 14) if optical elements like mirrors, lenses, etc. influence the geometry of the radiation propagation between the source and the observer.

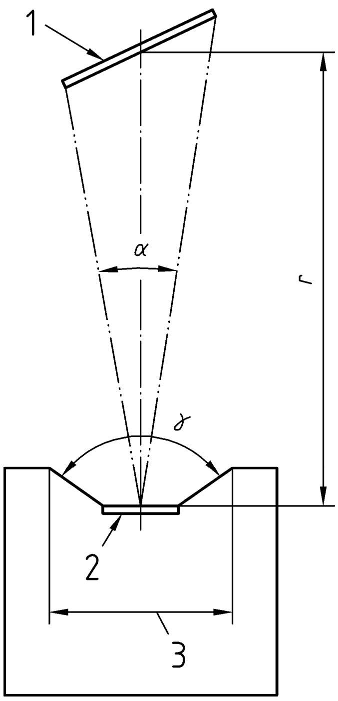
3.2.21
viewing distance
r
distance between the centre of the source and the point of observation (see Figure 1)

NOTE For lamps radiating in all directions the distance is measured from the centre of the filament or arc source. For reflector-type lamps the distance is measured from the outside edge of the lens or the plane defining the end of the reflector in a lens free reflector (see CIE S 009).

3.2.22
viewing angle
ϕ
angle between the normal of the source and the line of sight (see Figure 1)

3.2.23
angle of acceptance
γ
largest plane angle between all directions in which a radiation detector is sensitive (see Figure 2)

NOTE 1 In practical applications the angle of acceptance is determined by both the choice of an aperture and the distance between this aperture and the detector.



Key
1 source
2 detector
3 aperture

Figure 2 — Angle of acceptance γ of the detector and angular subtense α of the source (simplified drawing)

NOTE 2 The angle of acceptance γ, is a property of a radiation detector. It should not be confused with the angular subtense α, which is a property of the radiation source.

3.2.24
standard erythema dose
SED
standardised measure of erythemogenic UV radiation

NOTE 1 1 SED is equivalent to an erythemal effective radiant exposure of 100 Jm-2.

NOTE 2 This definition of the standard erythema dose is taken from ISO/CIE 17166.

3.2.25
minimal erythema dose
MED
UV-radiation dose that produces a just noticeable erythema on an individual person (see [9])

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 hours), 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/m^2 or in SED.

3.2.26
solar global UV index
I_{UV}
quantity for the erythemal potential of the ambient solar UV radiation, given by:

$$I_{UV} = k_{er} \int_{250nm}^{400nm} E_{\lambda}(\lambda) s_{er}(\lambda) \, d\lambda \quad (15)$$

where

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

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

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

NOTE 1 This is a simplified definition. The full definition of the solar global UV index can be found in CIE S 013/E which is based on the recommendations of WHO/WMO/UNEP/ICNIRP [12].

NOTE 2 The global 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.

3.2.27
non-melanoma skin cancer weighting function
$s_{nmsc}(\lambda)$
spectral weighting function reflecting the spectral dependency of the risk of induction of non-melanoma skin cancer by UV-exposure

NOTE Values for this function are specified in CIE DS 019.2/E within a wavelength range from 250 nm to 400 nm.

3.2.28
non-melanoma skin cancer irradiance
E_{nmsc}
irradiance spectrally weighted with the non-melanoma skin cancer weighting function $s_{nmsc}(\lambda)$, given by:

$$E_{nmsc} = \int_{\lambda_1}^{\lambda_2} E_{\lambda}(\lambda) s_{nmsc}(\lambda) d\lambda \quad (16)$$

3.2.29
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:

$$H_{nmsc} = \int_{\lambda_1}^{\lambda_2} H_\lambda(\lambda) s_{nmsc}(\lambda) d\lambda \quad (17)$$

or

$$H_{nmsc} = \int_{\Delta t_{exp}} E_{nmsc}(t) dt \quad (18)$$

3.2.30
angular subtense of the apparent source
α
plane angle under which a source is seen from the point of observation, given by:

$$\alpha = D_{app} / r \quad (19)$$

NOTE The angular subtense is sometimes called the "visual angle" (see CIE S 009). It should not be confused with the "viewing angle" which has a different meaning (see 3.2.22).

3.2.31
erythemal effective irradiance
E_{er}
irradiance spectrally weighted with the erythemal weighting function $s_{er}(\lambda)$, given by:

$$E_{er} = \int_{250nm}^{400nm} E_\lambda(\lambda) s_{er}(\lambda) d\lambda \quad (20)$$

where

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

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

NOTE The erythemal effective irradiance is defined in ISO/CIE 17166.

3.2.32
erythemal effective radiant exposure
H_{er}
radiant exposure spectrally weighted with the erythemal weighting function $s_{er}(\lambda)$, given by:

$$H_{er} = \int_{\Delta t_{exp}} \int_{250nm}^{400nm} E_\lambda(\lambda, t) s_{er}(\lambda) d\lambda dt \quad (21)$$

where

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

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

Δt_{exp}, is the exposure duration.

NOTE The erythemal effective radiant exposure is defined in ISO/CIE 17166.

4 Relationships between quantities

NOTE Some useful relationships between quantities are provided in this clause. Together with the definitions in clause 3 of this standard and in other reference sources, these relationships will help to apply parts 1, 2 and 3 of EN 14255.

4.1 Irradiance *E*

Can be calculated from the spectral irradiance by:

$$E = \int_{\lambda_1}^{\lambda_2} E_\lambda(\lambda) d\lambda \qquad (22)$$

4.2 Radiant exposure *H*

Calculated either from the integral of the spectral radiant exposures with respect to the wavelength-range:

$$H = \int_{\lambda_1}^{\lambda_2} H_\lambda(\lambda) d\lambda \qquad (23)$$

Or calculated from the integral of the irradiance *E,* with respect to the exposure duration Δt_{exp}:

$$H = \int_{\Delta t_{\mathrm{exp}}} E(t)\,\mathrm{d}t \qquad (24)$$

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[13] CIE 151:2003, *Spectral weighting of solar ultraviolet radiation, ISBN 3 901 906 20 7*

[14] CIE 17.4, *International Lighting Vocabulary; Chapter 845: Lighting*

NOTE The International Lighting Vocabulary is currently under revision.

[15] CIE 106, *CIE collection in photobiology and photochemistry*

[16] CIE S 009/E:2002, *Photobiological safety of lamps and lamp systems*

[17] CIE S 013/E, *International Standard Global Solar UV Index*

[18] CIE DS 019.2/E, *Photocarcinogenesis Action spectrum (Non-Melanoma Skin cancers)*

[19] ILO/ICNIRP Guide, *Protecting outdoor workers from solar ultraviolet radiation (in preparation)*

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

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