# TECHNICAL REPORT

# IEC TR 60825-9

First edition
1999-10

**Safety of laser products –**

**Part 9:**
**Compilation of maximum permissible exposure to incoherent optical radiation**

*Sécurité des appareils à laser –*

*Partie 9:*
*Exposition maximale admissible au rayonnement lumineux incohérent*



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For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to publications IEC 60027: *Letter symbols to be used in electrical technology*, IEC 60417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets* and IEC 60617: *Graphical symbols for diagrams*.

* See web site address on title page.

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International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http://www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# SAFETY OF LASER PRODUCTS –

# Part 9: Compilation of maximum permissible exposure to incoherent optical radiation

## FOREWORD

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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 60825-9, which is a technical report, has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

The text of this technical report is based on the following documents:

| Enquiry draft | Report on voting |
|---|---|
| 76/171/CDV | 76/204/RVC |

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

This document which is purely informative is not to be regarded as an International Standard.

**SAFETY OF LASER PRODUCTS –**

**Part 9: Compilation of maximum permissible exposure to incoherent optical radiation**

## 1 Scope and Object

This Technical Report reconciles current **M**aximum **P**ermissible **E**xposure (MPE) values for the exposure of the human eye and skin to incoherent optical radiation from artificial sources in the wavelength range from 180 nm to 3000 nm with the ultimate goal of harmonisation. Exposure limits between 3000 nm and 1 mm wavelength are currently undefined.

These values are based on the best available information from experimental studies and should be used only as guides in the control of exposure to radiation from artificial sources and should not be regarded as a precise line between safe and dangerous levels.

NOTE The values of this report are applicable to most individuals, however, some individuals may be hypersusceptible or otherwise unusually responsive to optical radiation because of genetic factors, age, personal habits (smoking, alcohol, or other drugs), medication, or previous exposures. Such individuals may not be adequately protected from adverse health effects from exposure to optical radiation at or below the maximum permissible exposure values of this report. Medical advise should be sought to evaluate the extent to which additional protection is needed.

These values were mainly developed for exposure to artificial sources. They may also be used for the evaluation of exposure to sunlight.

The MPE values should not be applicable to exposure of patients to optical radiation for the purpose of medical treatment.

Maximum permissible exposure values for the exposure to radiation from laser sources are defined in IEC 60825-1.

NOTE 1 Basic documents of this report were IEC 60825-1 (addressing lasers) and the IRPA/ICNIRP Guidelines (addressing incoherent sources). ACGIH limits are slightly different in wavelength ranges and in limit values.

NOTE 2 In spite of the fact that LEDs emit mainly incoherent radiation they are currently dealt with in IEC 60825-1.

NOTE 3 There are no damage mechanisms which are known to be different for coherent and incoherent sources. However, in many cases the limit values in IEC 60825-1 are more conservative than the values in this report. This is especially true in wavelength regions where no lasers were available when IEC 60825-1 was originally developed.

NOTE 4 Exposures to levels at the MPE values given may be uncomfortable to view or feel upon the skin.

NOTE 5 In the UV-B and UV-C spectral ranges the MPE values approach the radiant exposures producing minimally detectable biological changes in the surface corneal cells. Levels producing harmful effects are 2 to 3 times greater.

**1.1** The object of this technical report is to provide guidance for the protection of persons from incoherent optical radiation in the wavelength range from 180 nm to 1 mm by indicating safe levels of optical radiation which are believed to be safe for most individuals in the sense that exposure at or below these levels will create no adverse effects. Because only limited knowledge exists about the effects of a long-term exposure, most MPEs are based on acute effects of the optical radiation exposure during an eigth hours work day.

**1.2** To provide procedures and methods how the level of optical radiation should be measured and evaluated for the purpose of comparison with the maximum permissible exposure.

## 2 Reference documents

IEC 60050(845):1987, *International Electrotechnical Vocabulary – Chapter 845: Lighting*

IEC 60825-1:1993, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide*
Amendment 1:1997*

ISO 1000:1992, *SI units and recommendations for the use of their multiples and of certain other units*

ISO 11145:1994, *Optics and optical instruments – Lasers and laser-related equipment – Vocabulary and symbols*

ISO/IEC Guide 51:1997, *Safety aspects – Guidelines for their inclusion in standards*



* There is a consolidated edition 1.1 (1998) that includes IEC 60825-1 (1993) and its amendment 1 (1997).

# 3 Definitions

For the purposes of this report, the following definitions apply. Basic definitions are given in ISO 1000:1992, ISO 11145:1994 and IEC 60050(845):1987. Some of these definitions are repeated, as well as some definitions from IEC 60825-1 and from ISO/IEC Guide 51. Departures from the basic documents are intentional.

(In the following, → means "see")

**3.1**
**angular magnification M**
angular magnification M of an optical instrument is the ratio of the → visual angle subtended by the object with the instrument ($\alpha_{instr}$) to the visual angle subtended at the eye by the object without the instrument ($\alpha_{eye}$)

$$M = \frac{\alpha_{instr}}{\alpha_{eye}}$$

NOTE In technical optics the visual angle subtended without optical instruments is usually based on a comfortable visual distance of 25 cm. In this report the minimum viewing distance is considered to be not smaller than 10 cm.

**3.2**
**angular subtense**
visual angle α subtended by the apparent source at the eye of an observer (see figure 1) or at the point of measurement (see also maximum angular subtense and minimum angular subtense)

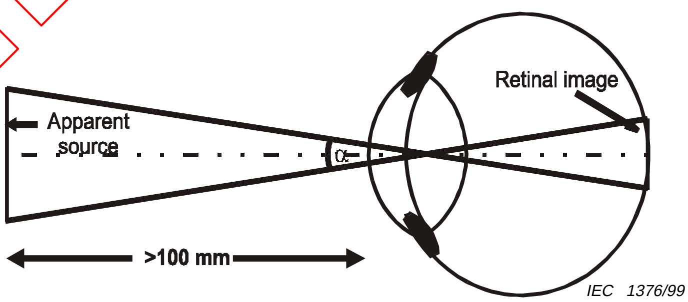


**Figure 1 – The definition of the angular subtense α of the apparent source**

Symbol: α
SI unit: radian

**3.3**
**aperture, aperture stop**
aperture stop is an opening serving to define the area over which radiation is measured (see also measurement aperture)

**3.4**
**apparent source**
real or virtual object (source of optical radiation) that forms the smallest possible retinal image

NOTE This definition is used to determine the location of the apparent origin of radiation in the wavelength range of 380 nm to 1400 nm, with the assumption of the apparent source being located in the eye's range of accommodation (usually ≥ 100 mm).

**3.5**
**blue light hazard**
potential for a photochemically induced retinal injury resulting from radiation exposure at wavelengths principally between 380 nm and 500 nm

**3.6**
**coherence**
characteristic of an electromagnetic field where there is a constant phase relationship between two points in space and time

**3.7**
**coherence length**
distance in beam propagation direction within which a constant phase relationship is retained

**3.8**
**diode emitter**
any semiconductor p-n junction device which can be made to produce electromagnetic radiation by radiative recombination in the semiconductor in the wavelength range from 180 nm to 1 mm

**3.9**
**exposure distance**
shortest distance from a radiation source to the nearest place of human exposure appropriate to the application

**3.10**
**exposure duration**
the duration of a pulse, or series, or train of pulses, or of continuous emission of radiation incident upon the human body consistent with the application

**3.11**
**incoherent**
radiation is considered incoherent if the coherence length is shorter than 1 mm

**3.12**
**infrared radiation**
for practical purposes any electromagnetic radiation within the wavelength range 780 nm to 1 mm. The infrared spectrum is divided into three spectral bands for photobiological safety purposes: →infrared A, →infrared B and →infrared C

**3.13**
**infrared A (IR-A)**
optical radiation for which the wavelengths fall in the spectral range from 780 nm to 1400 nm

**3.14**
**infrared B (IR-B)**
optical radiation for which the wavelengths fall in the spectral range from 1400 nm to 3000 nm

**3.15**
**infrared C (IR-C)**
optical radiation for which the wavelengths fall in the spectral range from 3000 nm to 1 mm

**3.16**
**intended use**
the use of a product, process or service in accordance with specifications, instructions and information provided by the supplier

**3.17**
**intermediate source**
basically, a source forming an image on the retina which is so large that heat flow in radial direction (perpendicular to the optical axis) from the centre of the image to the surrounding biological tissue is comparable to heat flow in axial directions (parallel to the optical axis)

By extension, an intermediate source is a source forming an image on the retina with a size larger than the size on which the maximum permissible exposure values for →*small sources* are based, up to the size of a →*large source*. This extension is needed because some eye movements are included in the MPEs as listed in the tables of this report

NOTE In this report an intermediate source in its *basic meaning* is subtending at the retina an angle between 1,5 mrad and 100 mrad, i.e. its image diameter on the retina lies between 25 μm and 1700 μm. These dimensions are applicable for exposure times less than 0,7 s.

In this report an intermediate source in its *extended meaning* is subtending at the retina an angle between 11 mrad and 100 mrad, i.e. its image diameter on the retina lies between 187 μm and 1700 μm. These dimensions are valid for exposure times longer than 10 s.

For exposure times between 0,7 s and 10 s the angle subtended by an intermediate source depends on the exposure time (see table 3).

**3.18**
**irradiance**
quotient of the →radiant power d*P* incident on an element of a surface devided by the area d*A* of that element:

$$E = \mathrm{d}P\,/\,\mathrm{d}A$$

Symbol: *E*
SI Unit: W / m²

**3.19**
**large source**
source forming an image on the retina which is so large that heat flow in radial direction (perpendicular to the optical axis) from the centre of the image to the surrounding biological tissue is small compared to heat flow in axial directions (parallel to the optical axis)

NOTE In this report a large source is subtending an angle of more than 100 mrad at the retina, i.e. the diameter of its image on the retina is larger than 1700 μm.

**3.20**
**light**
→visible radiation

**3.21**
**light emitting diode (LED)**
→diode emitter (The optical radiation of LEDs is produced primarily by the process of spontaneous emission)

**3.22**
**maximum angular subtense** ($\alpha_{max}$)
value of angular subtense of the apparent source above which the source is considered to be a →large source (see also table 3)

**3.23**
**maximum permissible exposure (MPE)**
value of exposure to the eye or skin which, under normal circumstances, is not expected to result in adverse biological effects. The MPE values are related to the wavelength of the radiation, the exposure duration, the tissue at risk and the dimensions of the exposure site. For visible and near infrared radiation in the range 380 nm to 1 400 nm, the angular subtense of the source defines the size of the retinal image

**3.24**
**measurement aperture**
circular area used for measurements of →irradiance, →radiant exposure, →radiance and →time integrated radiance. This aperture defines the area over which these quantities are averaged during measurements for comparison with the MPE values

**3.25**
**monochromatic radiation**
radiation characterized by a single wavelength as a single emission line of a low pressure gas discharge lamp. In practice, radiation of a very small wavelength band can be described by stating a single wavelength if the biological action spectrum does not vary significantly within this wavelength band

**3.26**
**optical radiation**
electromagnetic radiation at wavelengths between 100 nm and 1 mm. Ultraviolet radiation in the wavelength range below 180 nm (called vacuum UV) is strongly absorbed by the oxygen in the air. For the purpose of this report the wavelength band of optical radiation is limited therefore to wavelengths greater than 180 nm

NOTE Considering the radiation safety, the spectral range between 380 nm and 1400 nm needs special consideration since the eye transmits radiation in this spectral range to the retina, where due to focusing, the irradiance may be increased by several orders of magnitude compared to that at the cornea.

**3.27**
**photometric quantities**
all radiometric quantities have corresponding photometric quantities relating to the visual perception of light. For monochromatic radiation of a wavelength $\lambda$ the photometric quantities can be calculated from the radiometric quantities by multiplying with the relative spectral efficiency $V(\lambda)$ (see annex C) respectively $V'(\lambda)$ and the maximum spectral efficacy of radiation $K_m$ respectively $K'_m$

$$K_m = 683 \text{ lm / W for photopic vision and}$$

$$K'_m = 1700 \text{ lm / W for scotopic (night) vision}$$

The names of the corresponding radiometric and photometric quantities can be taken from table 1. The symbols are the same for both, if necessary they may be discriminated by the subscript e (energetic) for radiometric and the subscript v (visual) for photometric quantities.

**Table 1 – Comparative list of radiometric and photometric quantities**

| **Radiometric quantities** | | **Symbol** | **Photometric quantities** | |
|---|---|---|---|---|
| **Name** | **Unit** | | **Name** | **Unit** |
| Radiant power | W | $P$, $\Phi$ | Luminous flux | lm |
| Radiant energy | J | $Q$ | Quantity of light | lm · s |
| Irradiance | $W/m^2$ | $E$ | Illuminance | $lm/m^2$ = lx |
| Radiant exposure | $J/m^2$ | $H$ | Luminous exposure | lx · s |
| Radiance | $W/(sr \cdot m^2)$ | $L$ | Luminance | $lm/(sr \cdot m^2) = cd/m^2$ |
| Radiant intensity | W/sr | $I$ | Luminous intensity | lm/sr = cd |
| Time integrated radiance | $J/(sr \cdot m^2)$ | $L_i$ | Time integrated luminance | $lm \cdot s/(sr \cdot m^2)$ |

**3.28**
**pulse duration**
the maximum time increment measured between the half peak power points at the leading and trailing edges of a pulse

**3.29**
**radiance**

the radiance $L$ in a given direction at a given point is the quotient of the →radiant power $dP$ passing through that point and propagating within the →solid angle $d\Omega$ in a direction $\varepsilon$ divided by the product of the area of a section of that beam on a plane perpendicular to this direction ($\cos\varepsilon \cdot dA$) containing the given point and the solid angle $d\Omega$ (see figure 2):

$$L = \frac{dP}{d\Omega \cdot dA \cdot \cos\varepsilon} \quad (1)$$

The same definition holds for the →time integrated radiance $L_i$ if in (1) the radiant power $dP$ is replaced by the radiant energy $dQ$.

$$L_i = \frac{dQ}{d\Omega \cdot dA \cdot \cos\varepsilon} \quad (2)$$

NOTE 1 This definition is a simplified version of IEV 845-01-34, sufficient for the purpose of this report. In cases of doubt, the IEV definition should be followed.

NOTE 2 Radiance and time integrated radiance cannot be changed by optical instruments. However, if the radiance is measured in a first material with index of refraction $n_1$ and the radiance is wanted in a second material $L_2$ with an index of refraction $n_2$, the radiance in the first material $L_1$ has to be multiplied by the factor $(n_1/n_2)^2$: $\frac{L_2}{L_1} = \left(\frac{n_1}{n_2}\right)^2$. In the case of air ($n_1 = 1$) and the eye ($n_2 = 1{,}336$ for aqueous and vitreous) this factor equals to 0,56. For the evaluation of the MPEs the radiance has to be used as measured in air because this factor is already taken into account in the tables of this report.

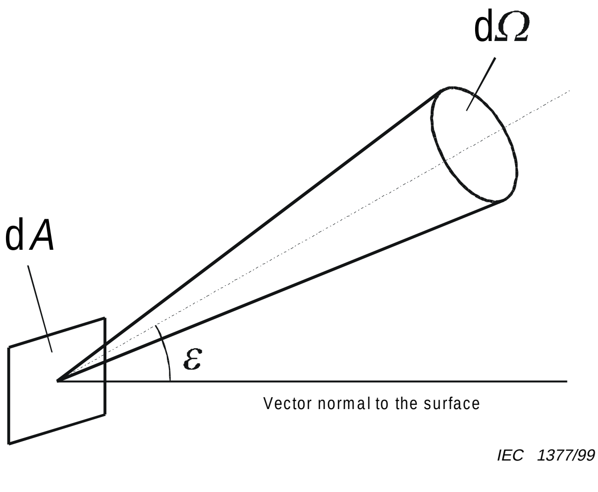


**Figure 2 – Definition of radiance**

Symbol of radiance: $L$
SI Unit of radiance: W / (m$^2$ · sr)

Symbol of time integrated radiance: $L_i$
SI Unit of time integrated radiance: J / (m$^2$ · sr)

**3.30**
**radiant energy**
time integral of the →radiant power *P* over a given duration *t*

$$Q = \int_0^t P \cdot dt \qquad (3)$$

Symbol: *Q*
SI Unit: Joule (J)

**3.31**
**radiant exposure**
the integral of the →irradiance over a given exposure time, i.e. the ratio of the radiant energy d*Q* incident on an element of a surface by the area d*A* of that element:

$$H = dQ / dA \qquad (4)$$

Symbol: *H*
SI Unit: Joule per square metre ($J / m^2$)

**3.32**
**radiant power** (flux)
power emitted, transferred, or received in the form of radiation (IEV 845-01-24)

Symbol: *P*, ($\Phi$)
SI Unit: Watt (W)

**3.33**
**reflectance**
ratio of the reflected radiant power to the incident radiant power in the given conditions (IEV 845-04-58)

Symbol: $\rho$
SI Unit: 1

**3.34**
**scanned radiation**
radiation having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference

**3.35**
**small source**
basically, a source forming an image on the retina which is so small that heat can easily flow in radial direction (perpendicular to the optical axis) from the centre of the image to the surrounding biological tissue

By extension, a source with an image size on the retina smaller than the size on which the maximum permissible exposure values are based. This extension is needed because some eye movements are included in the MPEs as listed in the tables of this report (see also 3.17 and 3.19)

NOTE In this report a small source in its basic meaning is subtending an angle of less than 1,5 mrad at the retina, i.e. the diameter of its image on the retina is less than about 25 µm. This size is applicable for exposure times less than 0,7 s.

A small source in its extended meaning is subtending an angle of less than 11 mrad at the retina, i.e. its diameter is less than about 187 µm. This size is applicable for exposure times longer than 10 s.

For exposure times between 0,7 s and 10 s the limiting angle depends on the exposure time (see table 3).

The term →"point source" cannot be used for small sources because it is prone to confusion: "point sources" may be a lot larger than what is usually considered to be a "point". In this report the term "small source" is therefore used in a similar sense.



**3.36**
**solid angle**
the solid angle with its vertex in the centre of a sphere with the radius *r*, is the ratio of the area *A* cut off by this angle of the surface of the sphere divided by the square of the radius (see figure 3):

$$\Omega = A / r^2$$

Symbol: $\Omega$
SI Unit: steradian (sr)

A full solid angle has 4π sr.

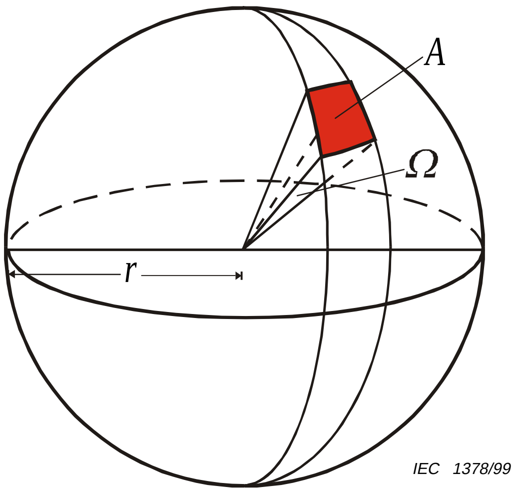


**Figure 3 – Definition of solid angle**

**3.37**
**spectral irradiance**
the ratio of the →radiant power d$P$ in a wavelength interval d$\lambda$ incident on an element of a surface by the area d$A$ of that element and by the wavelength interval d$\lambda$:

$$E_\lambda = \mathrm{d}P / (\mathrm{d}A \cdot \mathrm{d}\lambda)$$

Symbol: $E_\lambda$
SI Unit: W / m$^3$, usually expressed as W / (m$^2$ · nm)

**3.38**
**spectral radiance**
the spectral radiance $L_\lambda$ for a wavelength interval d$\lambda$ in a given direction at a given point is the quotient of the →radiant power $dP$ passing through that point and propagating within the →solid angle d$\Omega$ in a direction $\varepsilon$ divided by the wavelength interval d$\lambda$ and by the product of the area of a section of that beam on a plane perpendicular to this direction (cos $\varepsilon$ · d$A$) containing the given point and the solid angle d$\Omega$ (see figure 2):

$$L_\lambda = \frac{\mathrm{d}P}{\mathrm{d}\Omega \cdot \mathrm{d}\lambda \cdot \mathrm{d}A \cdot \cos\varepsilon}$$

Symbol: $L_\lambda$
SI Unit: W / (m$^3$ · sr), usually expressed as W / (m$^2$ · sr · nm)

**3.39**
**time integrated radiance**
the integral of the →radiance over a given exposure time expressed as radiant energy per unit area of a radiating surface per unit solid angle of emission

Symbol: $L_t$
SI Unit: J / (m$^2$ · sr)

**3.40**
**ultraviolet radiation**
for practical purposes, any radiation within the wavelength range from 100 nm to 400 nm. The ultraviolet spectrum is divided into three spectral bands for photobiological safety purposes: →ultraviolet A, →ultraviolet B and →ultraviolet C. Ultraviolet radiation at wavelengths less than 180 nm is called vacuum ultraviolet radiation

NOTE In many standards the long wavelength limit of the ultraviolet spectral range is fixed at 380 nm.

**3.41**
**ultraviolet A (UV-A)**
optical radiation for which the wavelengths fall in the spectral range from 315 nm to 400 nm (see also note above)

**3.42**
**ultraviolet B (UV-B)**
optical radiation for which the wavelengths fall in the spectral range from 280 nm to 315 nm

**3.43**
**ultraviolet C (UV-C)**
optical radiation for which the wavelengths fall in the spectral range from 100 nm to 280 nm

NOTE Ultraviolet radiation in the wavelength range below 180 nm (called vacuum UV) is strongly absorbed by the oxygen in the air. For the purposes of this report it is therefore sufficient to limit the lower end of the wavelength range of UV-C to 180 nm.

**3.44**
**visible radiation (light)**
any optical radiation capable of causing a visual sensation directly (IEV 845-01-03)

NOTE In this report, this is taken to mean electromagnetic radiation for which the wavelength of the monochromatic components lies between 380 nm and 780 nm.

**3.45**
**visual angle**
the angle subtended (see 3.2) by an object or detail at the point of observation. It usually is measured in radians, milliradians, degrees or minutes of arc



# 4 Maximum permissible exposure

## 4.1 General remarks

Maximum permissible exposure (MPE) values are set below known hazard levels, and are based on the best available information from experimental studies. They apply to exposure within any 8-hour period. The MPE values should be used as guides in the control of exposures and should not be regarded as precisely defined dividing lines between safe and dangerous levels. These limit values do not apply to photosensitive individuals or to individuals concomitantly exposed to photosensitizing agents.

## 4.2 Measurement aperture

An appropriate aperture has to be used for all measurements and calculations of exposure values. This is the measurement aperture and is defined in terms of the diameter of a circular area over which the irradiance or radiant exposure is to be averaged. Values for these apertures are shown in table 2.

Larger measurement apertures than those given in the table may be used if the irradiance is uniform over the diameter of the measurement aperture and the sensitivity of the detector system makes it necessary. However, with sources of optical radiation that do not produce a uniform optical radiation pattern (i.e. contain hot spots), the apertures according to the table should be used to assess the effect of hot spots.

When evaluating the MPEs of the skin it is recommended to use detectors having a response proportional to the cosine of the angle of incidence of the radiation.

The values of ocular exposures to radiation in the wavelength range from 380 nm to 1400 nm should be measured over a 7 mm diameter aperture (eye pupil).

**Table 2 – Minimum aperture diameter applicable to measuring irradiance, radiant exposure, radiance and time integrated radiance**

| MPEs applicable for the spectral range | See clause | Exposure duration | Diameter of the measurement aperture in the case of an exposure of the | |
|---|---|---|---|---|
| | | | Eye<br>mm | Skin<br>mm |
| 180 nm to 400 nm | 4.8.1 | $t \leq 3$ s | 1 | 1 |
| 180 nm to 400 nm | 4.8.1 | $t > 3$ s | 7 | 7 |
| >380 nm to 1400 nm | 4.8.2.1, 4.8.2.2 | any | 7 | 3,5 |
| >1400 nm to 3000 nm | 4.8.2.3 | $t \leq 3$ s | 1 | 1 |
| >1400 nm to 3000 nm | 4.8.2.3 | $t > 3$ s | 3,5 | 3,5 |

## 4.3 Pupil diameter

The MPE values applicable to the eye in the wavelength range from 380 nm to 1400 nm given in 4.8.2 are based on a standard pupil diameter $d_s$ of 7 mm for times <0,5 s and 3 mm for times >0,5 s. Depending on the luminance of the visual field, the diameter of the eye pupil varies between less than 2 mm and more than 7 mm. The pupil diameter varies also from individual to individual, with the visual task, age, etc. The following formula may be used for the calculation of the pupil diameter $d_p$ (measured in mm) from the mean luminance $L$ (measured in cd/m²) of the object looked at:

$$d_p = 1{,}29\ \text{mm} + \frac{6{,}62\ \text{mm}}{1 + \left(\dfrac{L}{8{,}24\ \text{cd/m}^2}\right)^{0{,}32}} \qquad (5)$$

Figure 4 shows this dependence of the pupil diameter on the luminance.

The adjustment of the MPEs in the wavelength range from 380 nm to 1400 nm and for times < 0,5 s in relation to the standard pupil diameter $d_s$ (pupil diameter used for MPE specifications) has to be proportional to the area of the pupil:

$$E_{MPE}(d_p) = E_{MPE}(d_s) \cdot \left(\frac{d_s}{d_p}\right)^2 \text{ or} \qquad (6)$$

$$H_{MPE}(d_p) = H_{MPE}(d_s) \cdot \left(\frac{d_s}{d_p}\right)^2 \text{ or} \qquad (7)$$

$$L_{MPE}(d_p) = L_{MPE}(d_s) \cdot \left(\frac{d_s}{d_p}\right)^2 \text{ resp.} \qquad (8)$$

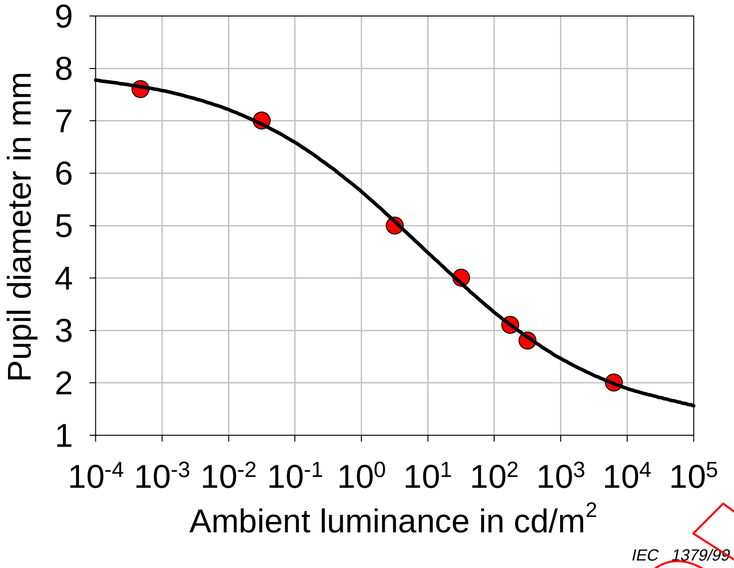


**Figure 4 – Dependence of pupil diameter on the luminance of the visual field according to Reeves**[1]

NOTE In cases where radiation sources are used under very different illumination conditions (e.g. during day, night, etc.), it will be most safe to evaluate the radiation safety for a 7 mm pupil diameter.



## 4.4 Repetitively pulsed, modulated or scanned radiation

Since there are only limited data on multiple pulse exposure criteria, caution must be used in the evaluation of exposure to repetitively pulsed radiation. Most of the commonly used sources are emitting continuous radiation. However, if the instantaneous value of the radiation output is repetitively falling below 10 % of its time averaged value the following methods should be applied.

For wavelengths <380 nm, the MPE is determined by using the most restrictive of the following requirements a) and b).

The MPE for wavelengths >380 nm is determined by using the most restrictive of requirements b) and c).

a) The radiant exposure $H_{sp}$ (respectively time integrated radiance $L_{sp}$) from any single pulse of a duration $t$ within a pulse train should not exceed the MPE $H_{MPE}$ ($L_{MPE}$) for a single pulse of the duration $t$:

$$H_{sp} \leq H_{MPE}(t) \qquad (9)$$

respectively

[1] see e.g. P. Reeves, JOSA **4**, 35-43 (1920)

$$L_{sp} \le L_{MPE}(t) \quad (10)$$

b) The time averaged irradiance $E_m$ (respectively radiance $L_m$) for a pulse train of duration $T$ should not exceed the MPE $E_{MPE}$ (respectively $L_{MPE}$) for a single pulse of duration $T$.

$$E_m \le E_{MPE}(T) \quad (11)$$

respectively

$$L_m \le L_{MPE}(T) \quad (12)$$

The average irradiance $E_m$ (respectively radiance $L_m$) for the exposure duration $T$ may be calculated by the following relations:

$$E_m = N \cdot H_{sp} / T \quad (13)$$

respectively

$$L_m = N \cdot L_{sp} / T \quad (14)$$

Where $N$ is the total number of pulses during the exposure of duration $T$.

c) The radiant exposure $H_{sp}$ (respectively time integrated radiance $L_{sp}$) from any single pulse of a duration $t$ within a pulse train should not exceed the MPE $H_{MPE}$ ($L_{MPE}$) for a single pulse of a duration $t$ multiplied by the correction factor $C_5$. This correction factor $C_5$ is only applicable to pulse durations shorter than 0,25 s:

$$H_{sp} \le H_{MPE}(t) \cdot C_5 \quad (15)$$

respectively

$$L_{sp} \le L_{MPE}(t) \cdot C_5 \quad (16)$$

where

$C_5$ = $N^{-1/4}$

$N$ = total number of pulses expected in an exposure.

These two equations are equivalent to the following equations:

$$\frac{H_{sp}}{H_{MPE}(t) \cdot C_5} = \frac{H_{sp}}{H_{MPE}(t)} \cdot N^{1/4} \le 1 \quad (17)$$

respectively

$$\frac{L_{sp}}{L_{\mathrm{MPE}}(t)\cdot C_5} = \frac{L_{sp}}{L_{\mathrm{MPE}}(t)}\cdot N^{1/4} \leq 1 \qquad (18)$$

Where a pulse train consists of pulses of different duration $t_\mathrm{i}$ or different single pulse radiant exposure $H_\mathrm{spi}$ (respectively time integrated radiance $L_\mathrm{spi}$), the following relations derived from (17) and (18) replace equations (15) and (16):

$$\sum N_i \cdot \left(\frac{H_{spi}}{H_{\mathrm{MPE}}(t_i)}\right)^4 \leq 1 \qquad (19)$$

respectively

$$\sum N_i \cdot \left(\frac{L_{spi}}{L_{\mathrm{MPE}}(t_i)}\right)^4 \leq 1 \qquad (20)$$

where

$N_i$ = number of pulses of duration $t_\mathrm{i}$

$N = \sum N_i$ = total number of pulses expected in an exposure.

In some cases the radiant exposure from a single pulse $H_\mathrm{sp}$ may fall below the MPE that would apply for continuous exposure at the same peak power using the same total exposure time. Under these circumstances the MPE for continuous exposure may be used.

## 4.5 Angular subtense of the source

The concept of a limiting →angular subtense of the →apparent source is used in the wavelength range from 380 nm to 1400 nm where the radiation can be focused by the refractive parts of the eye onto the retina.

Two limiting angular subtenses are used in this report: the angle determining the limit between →small sources and →intermediate sources (the minimum angular subtense $\alpha_{\mathrm{min}}$) and the angle determining the limit between intermediate sources and →large sources (the maximum angular subtense $\alpha_{\mathrm{max}}$).

Below the minimum angular subtense ($\alpha_{min}$) MPEs are independent of the source size. The value of $\alpha_{min}$ depends on the exposure duration *t* (see table 3).

NOTE The dependence of the minimum angular subtense on the exposure duration is due to the time dependence of eye movements. For times >10 s the energy will be spread over a larger area on the retina than for times <0,7 s. This angle $\alpha_{min}$ is equal to 11 mrad. For very long exposures of 1000 s and more, when task determined eye movements dominate, the angle is more than 100 mrad.

**Table 3 – Limiting angular subtense for the eye**

| | |
|---|---|
| $\alpha_{min}$ = 1,5 mrad | for $t < 0,7$ s |
| $\alpha_{min}$ = $2 \cdot t^{3/4}$ mrad | for $0,7 \text{ s} \leq t \leq 10$ s |
| $\alpha_{min}$ = 11 mrad | for $t \geq 10$ s |
| $\alpha_{max}$ = 100 mrad = 0,1 rad | |

Above the maximum angular subtense ($\alpha_{max}$) MPEs are independent of the source size. The value of $\alpha_{max}$ does not depend on the exposure time *t* (see table 3) and is in all cases 100 mrad.

Between the minimum angular subtense ($\alpha_{min}$) and the maximum angular subtense ($\alpha_{max}$) MPEs for retinal thermal hazard depend on the source size. Values expressed as radiance or time integrated radiance are inversely proportional to the source size. To describe this dependence of the MPEs on the source size, a correction factor $C_\alpha$ is used:

$C_\alpha = \alpha_{min}$ for $\alpha \leq \alpha_{min}$

$C_\alpha = \alpha$ for $\alpha_{min} < \alpha \leq \alpha_{max}$

$C_\alpha = \alpha_{max}$ for $\alpha_{max} < \alpha$

The values for the limiting angular subtense have to be used according to the applicable exposure duration, i.e. $\alpha_{min}$ = 1,5 mrad for single pulses shorter than 0,7 s, and $\alpha_{min}$ = 11 mrad for exposures durations longer than 10 s.

The angular subtense of an oblong source is determined by the arithmetic mean of the maximum and minimum angular dimensions of the source. Any angular dimension that is greater than $\alpha_{max}$ or less than 1,5 mrad should be limited to $\alpha_{max}$ or 1,5 mrad respectively, prior to determining the mean.

The angular subtense of the source is determined at the distance of expected exposure. The closest distance at which the human eye can sharply focus is about 100 mm. At shorter distances the image of a light source would be out of focus and blurred. No shorter distance than 100 mm is used therefore in this report for the determination of the angular subtense of a source.

## 4.6 Time basis

Any evaluation of compliance with the MPEs should be based on the expected exposure duration. When looking into bright sources having a luminance > $10^4$ cd/m$^2$ natural aversion response would limit the exposure to 0,25 s. Where the MPEs expressed in J/m$^2$ and exposures longer than 8 hours are expected, there is evidence that under normal extended exposure conditions it is sufficient to integrate in the ultraviolet spectral range the irradiance over 8 hours and to apply the 8-hour MPE.

## 4.7 Radiance and irradiance

In the following section some MPE values are expressed as radiance (respectively time integrated radiance), some are expressed as irradiance (respectively radiant exposure).

To calculate the irradiance $E$ from the radiance $L$ for an angle $\varepsilon = 0$ (see 3.29) one has to multiply by the solid angle $\Omega$ subtended by the source at the eye:

$$E = L \cdot \Omega \qquad (21)$$

This relation holds for small solid angles $\Omega$. The more general expression is:

$$\mathrm{d}E = L \cdot \mathrm{d}\Omega \qquad (22)$$

For small circular sources, the following relation holds between the plane angle $\alpha$ and the solid angle $\Omega$:

$$\Omega = \frac{\alpha^2 \cdot \pi}{4} \qquad (23)$$

This leads to the following relation between the irradiance and the radiance for a given angular subtense $\alpha$:

$$E = L \cdot \frac{\alpha^2 \cdot \pi}{4} \qquad (24)$$

The equivalent relations hold between time integrated radiance and radiant exposure.

NOTE 1 An instrument measuring radiance normally measures the radiant power through a defined aperture and within a defined angle of acceptance. When applying these relations to the MPEs expressed as radiance in this report, the solid angle $\Omega$ of measurement should be calculated using $\alpha_{min}$.

NOTE 2 When MPEs expressed as radiance are to be measured as irradiance using these relations, the irradiance measurement should be performed with a solid angle $\Omega$ corresponding to at least the source size $a$, but not larger than $(\alpha^2_{min} \pi)/4$.

## 4.8 Maximum permissible exposure of the eye

### 4.8.1 Ultraviolet spectral range

#### 4.8.1.1 Spectral range between 180 nm and 400 nm

In the spectral range between 180 nm and 400 nm the effective irradiance $E_{eff}$ respectively radiant exposure $H_{eff}$ of a source has to be calculated using the following weighting formula:

$$E_{eff} = \sum_{180\text{ nm}}^{400\text{ nm}} E_\lambda(\lambda) \cdot S(\lambda) \cdot \Delta\lambda \qquad (25)$$

respectively

$$H_{eff} = \sum_{180\text{ nm}}^{400\text{ nm}} H_\lambda(\lambda) \cdot S(\lambda) \cdot \Delta\lambda \qquad (26)$$

where $E_\lambda(\lambda)$ is the spectral irradiance, $H_\lambda(\lambda)$ is the spectral radiant exposure, $S(\lambda)$ is the relative spectral effectiveness (see annex B and figure 5), and $\Delta\lambda$ is the spectral bandwidth.

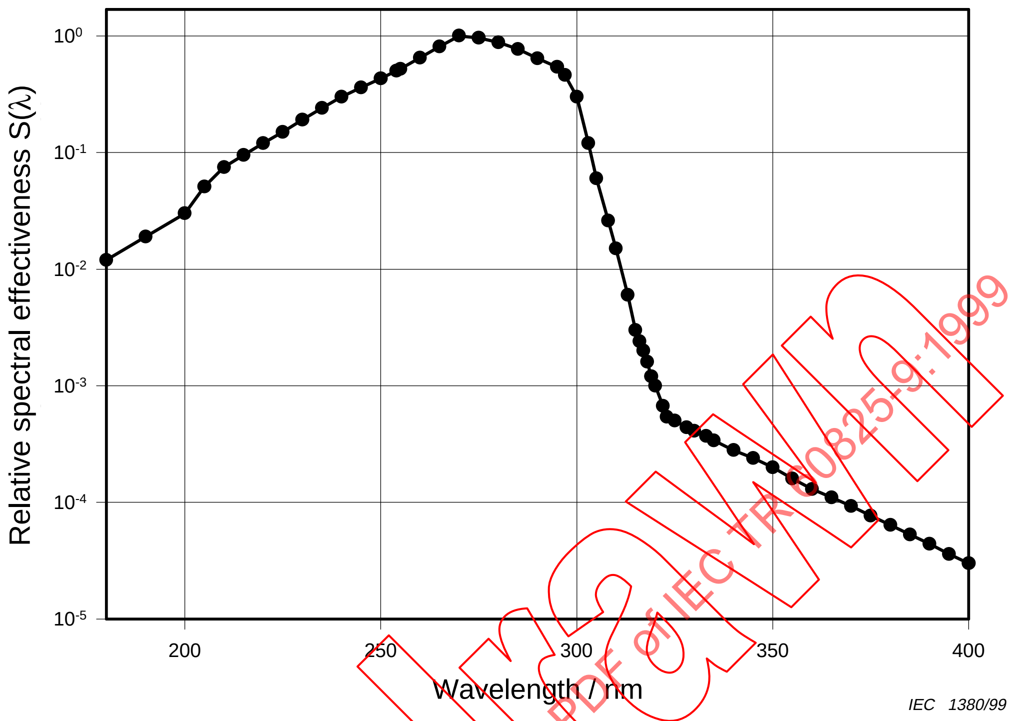


**Figure 5 – Relative spectral effectiveness $S(\lambda)$**

**Table 4 – Maximum Permissible Exposure to UV radiation**

| Duration of exposure per day | Maximum permissible effective irradiance $E_{eff}$ W/m² |
|---|---|
| 8 h | 0,001 |
| 4 h | 0,002 |
| 2 h | 0,004 |
| 1 h | 0,008 |
| 30 min | 0,017 |
| 15 min | 0,033 |
| 10 min | 0,05 |
| 5 min | 0,1 |
| 30 s | 1 |
| 10 s | 3 |
| 1 s | 30 |
| 0,5 s | 60 |
| 0,1 s | 300 |

The maximum permissible effective radiant exposure $H_{eff}$ is given by

$$H_{eff} = 30\ \text{J}/\text{m}^2 \qquad (27)$$

For a given effective irradiance the permissible exposure time $t_{max}$ in seconds, for exposure to ultraviolet radiation incident upon the unprotected eye is determined by:

$$t_{max} = \frac{30\ \text{J}/\text{m}^2}{E_{eff}} \qquad (28)$$

The exposure time may also be taken from table 4 which provides maximum permissible effective irradiance for a given exposure duration per day.

**4.8.1.2** Spectral range between 315 nm and 400 nm

The maximum permissible total radiant exposure within an 8-hour period in the spectral range from 315 nm to 400 nm is

$$H_{UV} = 10^4\ \frac{\text{J}}{\text{m}^2} \qquad (29)$$

NOTE In the wavelength range from 315 nm to 400 nm ACGIH extends the $10^4$ J/m² radiant exposure limit to 1000 s only and specifies for longer times a limit value of 10 W/m².

### 4.8.2 Visible and infrared spectral ranges

The following three hazard functions should be evaluated: the *Retinal Thermal Hazard*, the *Retinal Blue-Light Photochemical Hazard* and the *Infrared Radiation Hazard* to the cornea and the lens. The most restrictive one of these determines the risk caused by the source.

The maximum permissible exposure values of 4.8.2.1 and 4.8.2.2 are averaged over the standard pupil diameter of 4.3.

**4.8.2.1** Retinal Thermal Hazard (380 nm to 1400 nm)

To determine the effective radiance $L_{RTH}$ of a source for the wavelength range from 380 nm to 1400 nm, the following weighting formula should be used:

$$L_{RTH} = \sum_{380\ nm}^{1400\ nm} L_{\lambda}(\lambda) \cdot R(\lambda) \cdot \Delta\lambda \qquad (30)$$

where $L_{\lambda}(\lambda)$ is the spectral radiance, $R(\lambda)$ is the retinal thermal hazard function (see annex A and figure 6), and $\Delta\lambda$ is the spectral bandwidth.

To protect the human retina from thermal injury, the maximum permissible effective radiance $L_{RTH}$ for exposure durations $t$:

$$10\ s < t \qquad L_{RTH} = \frac{2{,}8 \cdot 10^4}{C_{\alpha}} \quad \frac{W}{m^2 \cdot sr} \qquad (31)$$

$$18\ \mu s \leq t \leq 10\ s \qquad L_{RTH} = \frac{5 \cdot 10^4}{C_{\alpha} \cdot t^{1/4}} \quad \frac{W}{m^2 \cdot sr} \qquad (32)$$

$$t < 18\ \mu s \qquad L_{RTH} = \frac{41{,}2}{C_{\alpha} \cdot t^{0{,}9}} \quad \frac{W}{m^2 \cdot sr} \qquad (33)$$

where $t$ is the exposure duration in seconds and $C_{\alpha}$ is the correction factor according to 4.5 in radian.

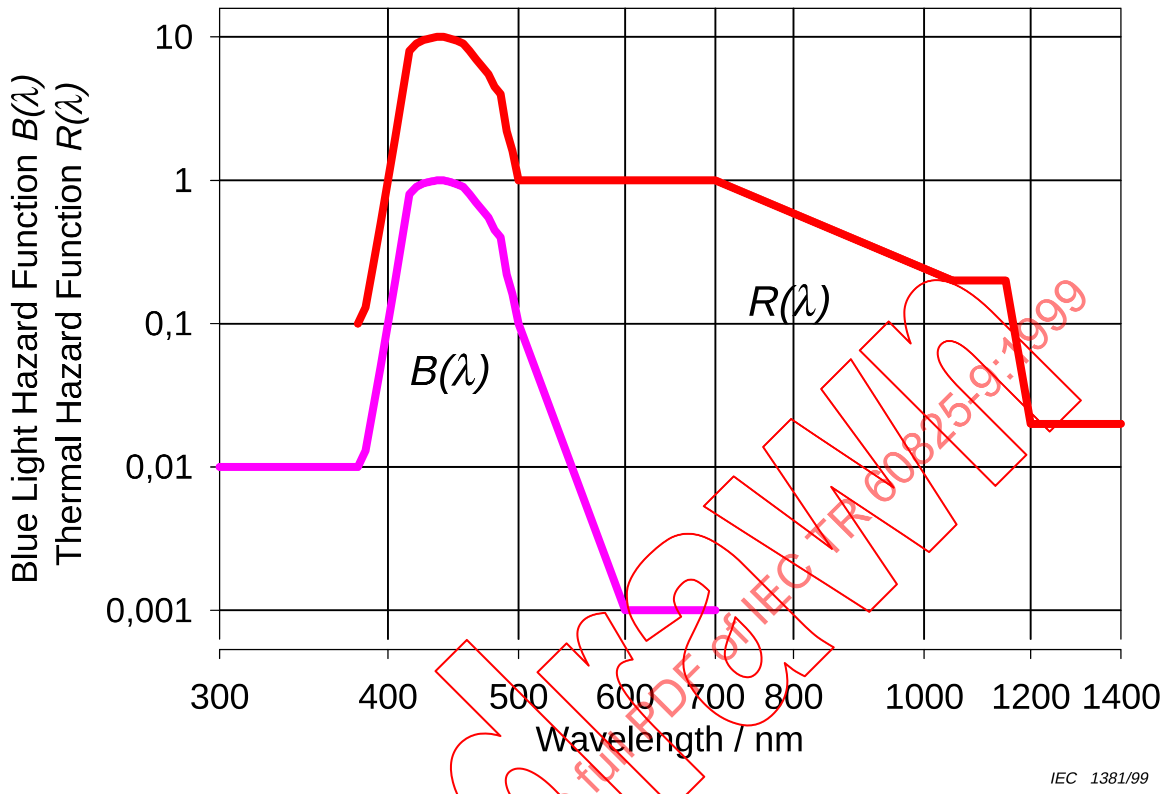


**Figure 6 – Retinal thermal hazard function *R*(λ) and retinal blue light hazard function *B*(λ)**



The maximum permissible radiance determined using these functions for $\alpha_{min}$ respectively $\alpha_{max}$ is shown for wavelengths between 1050 nm and 1150 nm in figure 7.

For any source having an angular subtense α greater than 0,1 rad these equations reduce to:

10 s < $t$ $$L_{RTH} = 2,8 \cdot 10^5 \frac{W}{m^2 \cdot sr} \quad (34)$$

18 µs ≤ $t$ ≤ 10 s $$L_{RTH} = \frac{5 \cdot 10^5}{t^{1/4}} \frac{W}{m^2 \cdot sr} \quad (35)$$

$t$ < 18 µs $$L_{RTH} = \frac{412}{t^{0,9}} \frac{W}{m^2 \cdot sr} \quad (36)$$

where $t$ is the exposure duration in seconds.

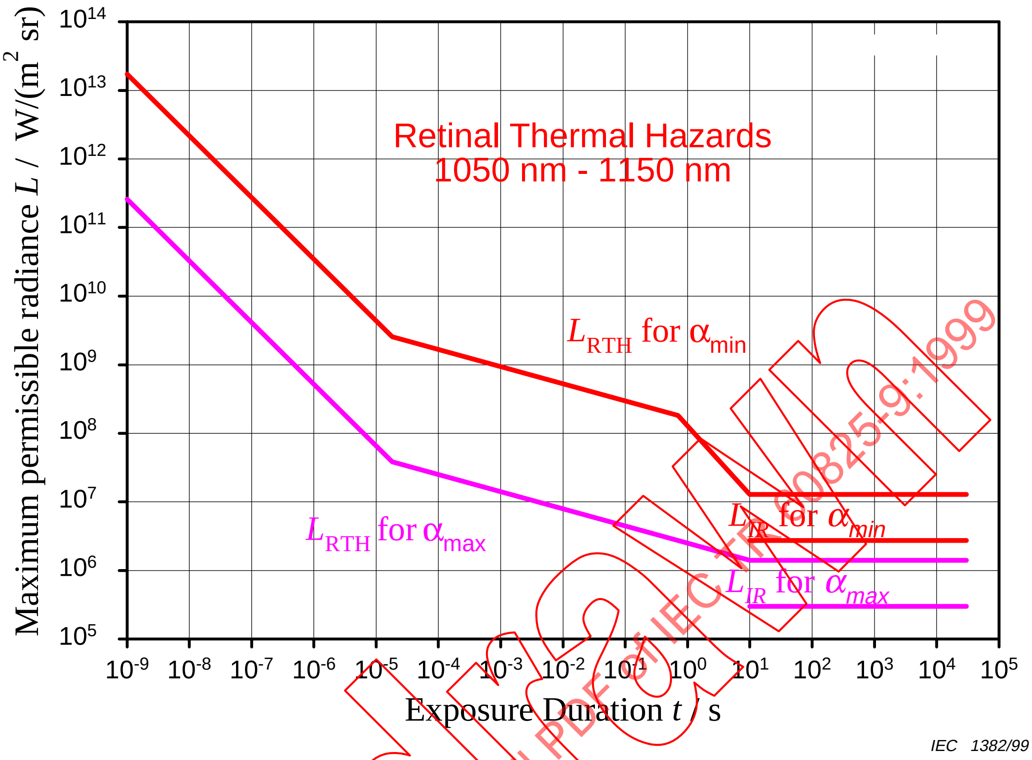


**Figure 7 – Time dependence of the maximum permissible radiance $L$ determined by $L_{IR}$ and $L_{RTH}$ using $\alpha_{min}$ respectively $\alpha_{max}$ for the wavelength range from 1050 nm to 1150 nm**



For infrared sources with a weak visual stimulus inadequate to activate the aversion response, the effective infrared radiance $L_{IR}$ is determined using the following formula (A weak visual stimulus is defined herein as one whose maximum luminance averaged over a circular field-of-view subtending 0,011 rad is less than 10 cd/m²):

$$L_{IR} = \sum_{780\text{ nm}}^{1400\text{ nm}} L_\lambda(\lambda) \cdot R(\lambda) \cdot \Delta\lambda \qquad (37)$$

where $R(\lambda)$ is the retinal thermal hazard weighting function (see annex A and figure 6) and $L_\lambda(\lambda)$ is the spectral radiance of the source.

To protect the human retina from thermal injury the maximum permissible effective infrared radiance $L_{IR}$ should be for:

$$t \geq 10 \text{ s} \qquad L_{IR} = \frac{6000}{C_{\alpha}} \frac{\text{W}}{\text{m}^2 \cdot \text{sr}} \tag{38}$$

where $C_{\alpha}$ is the correction factor according to 4.5 in radian.

This function is shown for $\alpha_{min}$ respectively $\alpha_{max}$ and wavelengths between 1050 nm and 1150 nm in figure 7.

For exposure durations shorter than 10 s equations (32) and (33) apply.

**4.8.2.2** Retinal Blue-Light Photochemical Hazard (300 nm to 700 nm)

To determine the effective blue-light radiance $L_B$ of a source, the following weighting formula should be used:

$$L_B = \sum_{300 \text{ nm}}^{700 \text{ nm}} L_{\lambda}(\lambda) \cdot B(\lambda) \cdot \Delta\lambda \tag{39}$$

where $L_{\lambda}(\lambda)$ is the spectral radiance and $B(\lambda)$ is the retinal blue-light hazard weighting function (see annex A and figure 6).

To protect the human retina from retinal blue-light injury, the maximum permissible effective radiance $L_B$ should be for:

$$t \leq 10\,000 \text{ s} \qquad L_B = \frac{1 \cdot 10^6}{t} \frac{\text{W}}{\text{m}^2 \cdot \text{sr}} \tag{40}$$

where $t$ is the exposure duration in seconds and for

$$t > 10\,000 \text{ s} \qquad L_B = 100 \frac{\text{W}}{\text{m}^2 \cdot \text{sr}} \tag{41}$$

NOTE For exposure durations shorter than 10 s, the limit value for the retinal thermal hazard $L_{RTH}$ is usually smaller than the limit value for the blue-light hazard.

When (32) is not satisfied, the maximum direct viewing duration $t_{max}$ is given by:

$$t_{max} = \frac{1 \cdot 10^6 \frac{J}{m^2 \cdot sr}}{L_B} \qquad (42)$$

To determine the effective blue-light irradiance $E_B$ of a source, the following weighting formula should be used:

$$E_B = \sum_{300\ nm}^{700\ nm} E_\lambda(\lambda) \cdot B(\lambda) \cdot \Delta\lambda \qquad (43)$$

where $E_\lambda(\lambda)$ is the spectral irradiance and $B(\lambda)$ is the retinal blue-light hazard weighting function (see Annex A and figure 6).

To protect the human retina from retinal blue-light injury by sources subtending an angle $\alpha$ < 0,011 rad the maximum permissible effective blue-light irradiance $E_B$ should be:

$$t \leq 10\,000\ s \qquad E_B = \frac{100 \frac{J}{m^2}}{t} \qquad (44)$$

$$t > 10\,000\ s \qquad E_B = 0{,}01 \frac{W}{m^2} \qquad (45)$$

where $t$ is the exposure duration.

To calculate the maximum direct viewing duration when (44) is not satisfied, this time $t_{max}$ is given by:

$$t_{max} = \frac{100 \frac{J}{m^2}}{E_B} \qquad (46)$$

#### 4.8.2.3 Infrared Radiation Hazard for cornea and lens (780 nm to 3000 nm)

To avoid a thermal hazard to the cornea and possible delayed effects upon the lens of the eye (cataractogenesis), in the spectral range between 780 nm and 3000 nm the total irradiance $E_{IR}$ should be limited for

$$t \geq 1000\,\text{s} \qquad E_{IR} = 100\ \frac{\text{W}}{\text{m}^2} \tag{47}$$

$$t < 1000\,\text{s} \qquad E_{IR} = \frac{1{,}8 \cdot 10^4}{t^{3/4}}\ \frac{\text{W}}{\text{m}^2} \tag{48}$$

where $t$ is the exposure duration in seconds.

In cold environments, these limits may be increased to 400 W/m$^2$ at 0 °C and 300 W/m$^2$ at 10 °C for applications where infrared sources are used for radiant heating.

The maximum permissible irradiance values of this section are averaged over the standard pupil diameter of 4.3, however the diameter of the measurement aperture should be taken according to table 2.

### 4.8.3 Overview on the maximum permissible exposure of the eye

The following table 5 gives an overview on the maximum permissible exposure values for the eye.

**Table 5 – Maximum permissible exposure of the eye**

| Quantity and Weighting Function | Exposure duration $t$ / s <br> Wavelength $\lambda$ / nm | $10^{-9}$ to $1,8 \times 10^{-5}$ | $1,8 \times 10^{-5}$ to 10 | 10 to $10^3$ | $10^3$ to $10^4$ | $10^4$ to $3 \times 10^4$ |
|---|---|---|---|---|---|---|
| $H_{eff} = \sum_{180\ \mathrm{nm}}^{400\ \mathrm{nm}} H_\lambda(\lambda) \cdot S(\lambda)\ \Delta\lambda$ | **180 to 400** | $30\ \frac{\mathrm{J}}{\mathrm{m}^2}$ | | | | |
| $H_{\mathrm{UV}} = \sum_{315\ \mathrm{nm}}^{400\ \mathrm{nm}} H_\lambda(\lambda) \cdot \Delta\lambda$ | **315 to 400** | $10^4\ \frac{\mathrm{J}}{\mathrm{m}^2}$ | | | | |
| $L_{\mathrm{B}} = \sum_{300\ \mathrm{nm}}^{700\ \mathrm{nm}} L_\lambda(\lambda) \cdot B(\lambda) \cdot \Delta\lambda$ | **300 to 700** | $\frac{1 \cdot 10^6}{t}\ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}}$ | | | | $100 \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}}$ |
| $L_{RTH} = \sum_{380\ nm}^{1400\ nm} L_\lambda(\lambda) \cdot R(\lambda) \cdot \Delta\lambda$ | **380 to 1400** | $\frac{41,2}{C_\alpha \cdot t^{0,9}}\ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}}$ | $\frac{5 \cdot 10^4}{C_\alpha \cdot t^{1/4}}\ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}}$ | $\frac{2,8 \cdot 10^4}{C_\alpha}\ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}}$ | | |
| $L_{IR} = \sum_{780\ nm}^{1400\ nm} L_\lambda(\lambda) \cdot R(\lambda) \cdot \Delta\lambda$ | **780 to 1400** <br> Source luminance <br> <10 cd/m² | | | $\frac{6000}{C_\alpha}\ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}}$ | | |
| $E_{IR} = \sum_{780\ nm}^{3000\ nm} E_\lambda(\lambda) \cdot \Delta\lambda$ | **780 to 3000** | $\frac{1,8 \cdot 10^4}{t^{3/4}}\ \frac{\mathrm{W}}{\mathrm{m}^2}$ | | | $100 \frac{\mathrm{W}}{\mathrm{m}^2}$ | |

## 4.9 Maximum permissible exposure of the skin

### 4.9.1 Ultraviolet spectral range (180 nm to 400 nm)

In the spectral range between 180 nm and 400 nm the effective irradiance $E_{eff}$ respectively radiant exposure $H_{eff}$ of a source has to be calculated using the following weighting formula:

$$E_{eff} = \sum_{180\ nm}^{400\ nm} E_{\lambda}(\lambda) \cdot S(\lambda) \cdot \Delta\lambda \tag{49}$$

respectively

$$H_{eff} = \sum_{180\ nm}^{400\ nm} H_{\lambda}(\lambda) \cdot S(\lambda) \cdot \Delta\lambda \tag{50}$$

where $E_{\lambda}(\lambda)$ is the spectral irradiance, $H_{\lambda}(\lambda)$ is the spectral radiant exposure, $S(\lambda)$ is the relative spectral effectiveness (see annex B and figure 5), and $\Delta\lambda$ is the spectral bandwidth.

The maximum permissible effective radiant exposure $H_{eff}$ is given by

$$H_{eff} = 30\ J/m^2 \tag{51}$$

For a given effective irradiance the permissible exposure time $t_{max}$ in seconds, for exposure to ultraviolet radiation incident upon the unprotected skin is determined by:

$$t_{max} = \frac{30\ J/m^2}{E_{eff}} \tag{52}$$

The exposure time may also be taken from table 4 which provides exposure times corresponding to a given effective irradiance.

### 4.9.2 Visible and infrared spectral ranges (380 nm to 3000 nm)

To protect the skin from thermal injury, in the spectral range between 380 nm and 3000 nm the maximum permissible radiant exposure $H$ for exposure durations $t < 10$ s is given by:

$$H = 2 \cdot 10^4 \cdot t^{1/4}\ J/m^2 \tag{53}$$

where $t$ is the exposure duration in seconds. This limit will prevent thermal skin burns.

No limit is provided for exposure durations longer than 10 s because normal avoidance behavior will impose limits on the duration of exposure. Limit values for much longer exposure durations are dominated by concerns of heat stress.

### 4.10 Photometric quantities

For some radiation sources the emission is characterised by photometric quantities (usually for photopic vision). If the emission is essentially monochromatic, the corresponding radiometric quantity can be calculated by dividing the photometric quantity by the relative spectral efficiency $V(\lambda)$ (see annex C) and the maximum spectral efficacy of radiation $K_m$ (see 3.27). For broadband sources this calculation is not possible if the spectral distribution of the emission of the source is not known.



## 5 Measurements

### 5.1 Measurement conditions

Measurements should be made under the following conditions:

**5.1.1** At points in space where human access is expected under reasonably foreseeable exposure conditions as determined by a risk assessment.

When evaluating the exposure of the eye, in the wavelength range from 380 nm to 1400 nm, the minimum distance of the measurement aperture from the apparent source should correspond to the minimum distance of intended use. However, it should not be less than 100 mm. The angular subtense $\alpha$ should be determined at the same distance from the apparent source.

**5.1.2** With the measuring instrument detector so positioned and so oriented as to result in the maximum detection of radiation by the instrument and averaged over a circular stop according to the measurement aperture applicable according to table 2.

**5.1.3** For the evaluation of $L_{RTH}$ and of $L_{IR}$ in the case of apparent sources subtending an angle $\alpha$ greater than $\alpha_{min}$ , a circular measurement aperture having a diameter of 7 mm (see also 4.2 and 4.3) and an effective angle of acceptance equal to $\alpha_{min}$ should be used for evaluating ocular MPEs. In order to detect hot spots, the source should be scanned.

**5.1.4** For the evaluation of $L_{RTH}$ and of $L_{IR}$ in the case of apparent sources subtending an angle $\alpha$ less than $\alpha_{min}$, a circular measurement aperture having a diameter of 7 mm and an effective angle of acceptance equal to $\alpha_{min}$ should be used for evaluating ocular MPEs.

**5.1.5** The time dependence of $\alpha_{min}$ needs only to be considered where exposure times between 0,7 s and 10 s become relevant. In most cases it will be sufficient to evaluate a source with the following two angles of acceptance: 1,5 mrad and 11 mrad.

**5.1.6** The retinal blue-light hazard should be evaluated with an angle of acceptance equal to $\alpha_{min}$. Since the retinal blue-light hazard is most restrictive only for longer exposure times (more than about 10 s), in most cases it will be sufficient to evaluate a source with an angle of acceptance of 11 mrad.

**5.1.7** In the case where the apparent source consists of multiple points or is a linear source or is a source of non-uniform radiance with an angular subtense greater than $\alpha_{min}$ and within the wavelength range from 380 nm to 1 400 nm, measurements or evaluations of the retinal thermal hazard should be done for every single point, or assembly of points, necessary to assure that the exposure does not exceed the MPE for each possible angle $\alpha$ subtended by each partial area, where $\alpha_{min} \leq \alpha \leq \alpha_{max}$, as well as for the whole source using an angle of acceptance not greater than $\alpha_{max}$.

**5.1.8** For the evaluation of the MPEs, the value of the angular subtense $\alpha$ of a linear source is determined by the mean of the smallest dimension of the source and of the largest dimension of the source. For calculating the mean, the smallest dimension should never been taken smaller than $\alpha_{min}$, the largest dimension never larger than $\alpha_{max}$.

**5.1.9** MPEs outside the wavelength range from 380 nm to 1400 nm and those applicable for the skin should be evaluated with a detector having a response proportional to the cosine of the angle of incidence of the radiation.

## 5.2 Measurement methods

The measurement methods described in the following are examples of possible simple methods only. Any other equivalent method may be used. Suitable measurement instruments with known measurement uncertainties are to be used for these measurements.

### 5.2.1 Measurement of (time integrated) radiance

As given by the definition, the (time integrated) →radiance $L$ ($L_i$) can be determined (see figure 8) by measuring the →radiant power $P$ passing through a defined measurement aperture stop having a surface area $A$ at a defined measurement distance. The plane angle of acceptance determines that part of the radiation source over which the radiance is averaged. This plane angle of acceptance $\alpha_a$ defines the →solid angle of acceptance $\Omega$ of the measurement set-up. For small circular sources, relation (23) between a plane angle $\alpha$ and the solid angle $\Omega$ may be used.

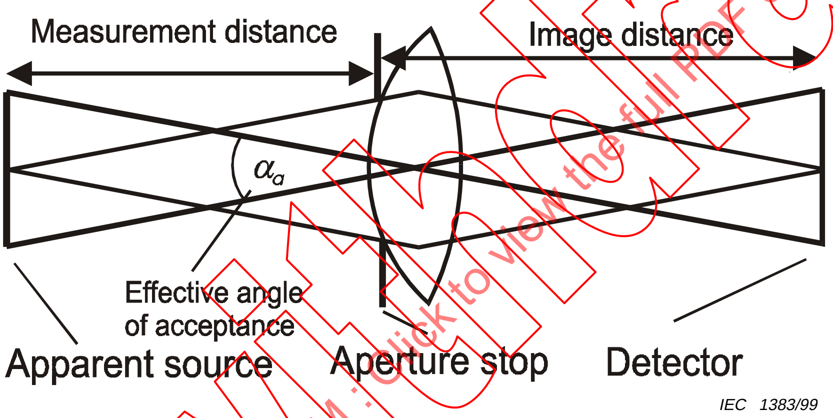


**Figure 8 – Measurement conditions for the measurement of (time integrated) radiance**

The radiance of the source is calculated from the →radiant power $P$ passing through the measurement aperture having a surface area $A$ and the solid angle $\Omega$:

$$L = \frac{P}{\Omega \cdot A} \qquad (54)$$

The time integrated radiance $L_i$ is measured in the same way; however, the measurement of the optical power $P$ is replaced by a measurement of the radiant energy $Q$.

$$L_i = \frac{Q}{\Omega \cdot A} \qquad (55)$$

### 5.2.2 Measurement of the dimensions of the apparent source

#### 5.2.2.1 Bare sources

In many cases, the physical dimensions of the radiating source are known. In these cases the dimensions of the apparent source are equal to the dimensions of the source.

Where the dimensions of the source are not known and the source is not accessible for measurements, the source has to be imaged by e.g. a lens. As an example, such a method is given in figure 9. The lens of focal length *f* should have a diameter sufficient to intercept the total radiation emitted by the source. Where this is not possible, the minimum diameter $d_l$ of the lens is given by the following relation:

$$d_l = 7\,\mathrm{mm} \cdot \frac{g}{100\,\mathrm{mm}} \qquad (56)$$

where *g* is the distance of the (first principal plane of the) lens from the source. These dimensions are shown in figure 9.

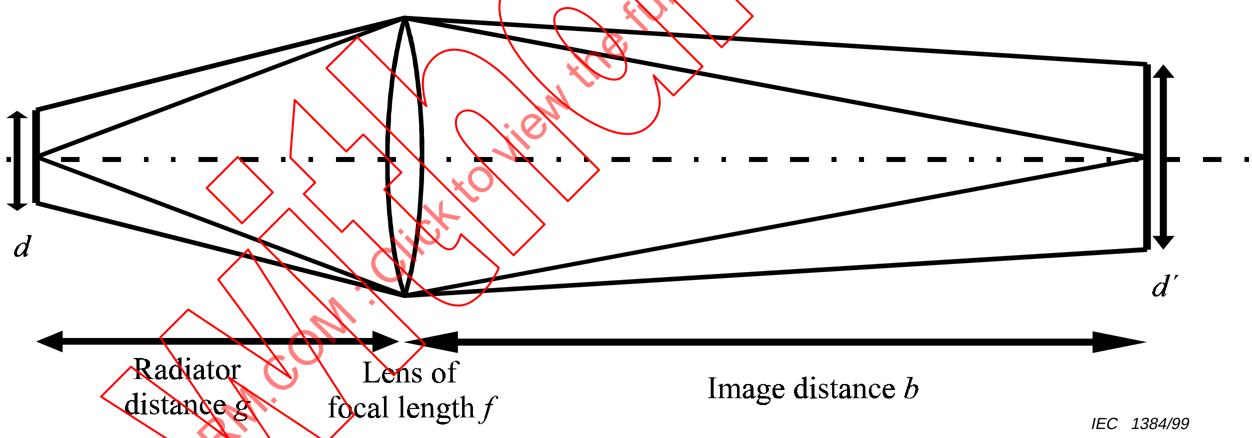


**Figure 9 – Determination of the angular subtense of the source**

If *b* is the distance of the image from the (second principal plane of the) lens, then the diameter *d* of the source is given by the relation

$$d = d' \cdot \frac{g}{b} \qquad (57)$$

where *d´* is the image diameter in the image plane. For the determination of *d´* the methods of 5.2.2.3 and 5.2.2.4 should be used.

### 5.2.2.2 Source/lens combinations

If the radiator consists of an assembly of a source and an optical element (e.g. a lens and/or a mirror), the distance of the source from the lens, the focal length of the optical element and the positions of the principal planes of the optical element are usually not known. In this case a set-up similar to figure 10 may be used to determine the angular subtense of the source. The diameter of the second lens has to be larger than the diameter of the radiator assembly. For the determination of *d´* the methods of 5.2.2.3 and 5.2.2.4 should be used.

The magnification *M* of the source is given by $M = 1 - \frac{a}{f_0} - \frac{b}{f} \cdot (1 - \frac{a}{f_0}) - \frac{b}{f_0}$,

where $f_0$ is the focal length of the lens of the radiator assembly and *a* is the distance between the right respectively left principal planes of the two lenses. Determining the image size *d´* with lenses of different focal lengths *f* and for several distances *a* between the two lenses, the two unknown quantities $f_0$ and *d* can be evaluated. If *a* is large enough, it would even not be necessary to determine it separately since the exact position of the principal plane of the unknown lens would scarcely contribute to the measurement error.



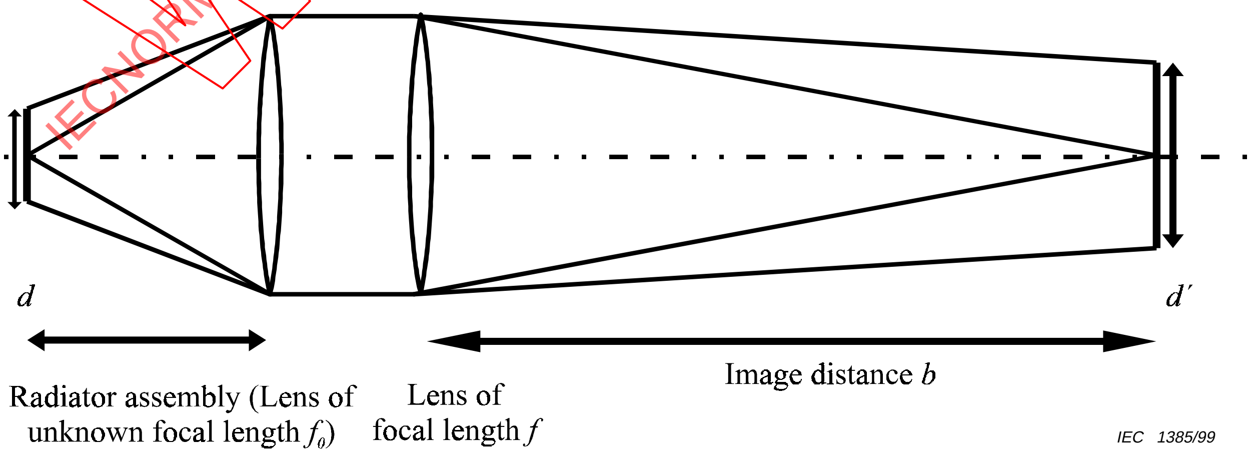


**Figure 10 – Determination of the angular subtense of the source**