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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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

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FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.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 (α_{instr}) to the visual angle subtended at the eye by the object without the instrument (α_{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)

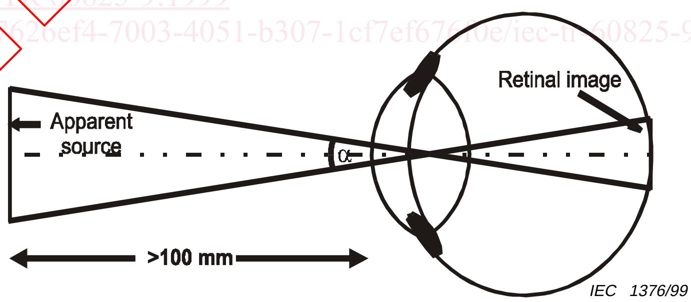

Figure 1 – The definition of the angular subtense α of the apparent source

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 (α_{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 λ 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, Φ	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 ε 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):

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

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:

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

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.

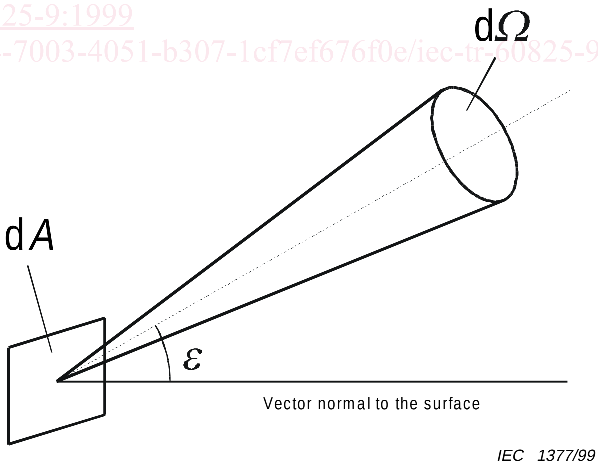

Figure 2 – Definition of radiance

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

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