TECHNICAL SPECIFICATION

IEC TS 60825-6

First edition
1999-07

Safety of laser products –

Part 6:
Safety of products with optical sources, exclusively used for visible information transmission to the human eye

Sécurité des appareils à laser –

Partie 6:
Sécurité des appareils avec des sources optiques, utilisés exclusivement pour la transmission d'information visuelle

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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

Commission Electrotechnique Internationale
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SAFETY OF LASER PRODUCTS –

Part 6: Safety of products with optical sources, exclusively used for visible information transmission to the human eye

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60825-6, which is a technical specification, has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

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

Enquiry draft	Report on voting
76/172/CDV	76/193/RVC

Full information on the voting for the approval of this technical specification 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.

Annexes A and B are for information only.

A bilingual version of this technical specification may be issued at a later date.

INTRODUCTION

Probably because of the increasing radiation power available from light emitting diodes (LEDs) and their physical similarity to laser diodes, these devices have been included in the scope of the laser safety standard IEC 60825-1. However, the optical radiation from LEDs differs in various aspects from laser sources; generally they lie between incoherent broadband sources and coherent laser sources.

The safety philosophy and classification requirements of IEC 60825-1, developed for coherent point sources (with the assumption of Gaussian radiation characteristics), have been transferred to incoherent intermediate sources (with typically Lambertian radiation characteristics) which are often made for intentional viewing. The result has been an overestimation of the real risk from this kind of source.

In Europe, and effective since January 1997, IEC 60825-1, which includes LEDs, is valid. Following the European product safety laws this means that each LED application or product has to be classified under single-fault conditions. LEDs in the visible wavelength range are increasingly used as a replacement for incandescent or fluorescent sources. However, contrary to conventional lamps, LEDs with the same or similar optical features for identical applications now have to be classified and potentially labelled.

Because this effectively discriminates against LED sources, technical committee 76 (jointly with subcommittee 100C) was established with the objective of preparing additional parts to the IEC 60825 series, for specific application-related requirements.

Due to problems with these LED sources the basic standard IEC 60825-1 is also under consideration and technical development. If a new edition of IEC 60825-1 with a changed safety philosophy becomes valid in the future, it will influence all subsidiary standards. This development will influence and/or change the basis for a more realistic assessment of the optical hazard of LEDs in the future. With this background, the value of this part could be temporary if a suitable treatment is developed in IEC 60825-1.

This technical specification is considered as a “prospective standard for provisional application” in the field of optical radiation safety of LEDs. This is because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

SAFETY OF LASER PRODUCTS –

Part 6: Safety of products with optical sources, exclusively used for visible information transmission to the human eye

1 Scope and object

This technical specification details the requirements, and provides an adapted hazard categorization scheme and specific guidance for the safe use of visible optical sources that are within the scope of IEC 60825-1, but used exclusively for transmission of information to the human eye. These application-related sources can be categorized into:

– type 1: safe for intended viewers and personnel in service and manufacturing activities;

– type 2: safe for intended viewers only (i.e. protective measures are required for users engaged in maintenance, service and manufacturing activities).

Applications of sources that cannot be categorized into either type must be treated in accordance with IEC 60825-1.

The peak wavelength range covered by this technical specification is limited to 400 nm to 700 nm, in accordance with the Class 2-limitation (safety by aversion reactions in the visible spectra range) in IEC 60825-1.

This technical specification covers only sources which are intended to be viewed directly. Indirectly visible sources such as illuminating sources or laserpointers are not covered.

In most cases the selected application group diode emitter sources, which include laser diodes and LEDs will be used. However, throughout this technical specification all sources covered by the scope are included whenever the words "diode emitter" are used.

The objectives of this technical specification are:

– to protect persons from optical radiation arising from products incorporating visible diode emitter sources, such as displays, indicators, electronic signs and signals;

– to lay down requirements for manufacturers and installers, in order that procedures can be established and information supplied to enable correct precautions to be taken;

– to ensure adequate warning of hazards associated with accessible optical radiation from visible sources;

– to reduce the potential for injury by minimizing unnecessary optical radiation, to give improved control of optical radiation through protective features, and to provide safe usage of products by specifying user control measures.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this technical specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical specification are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

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

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

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems*

3 Definitions

For the purpose of this technical specification, the following definitions apply. They repeat or supplement those given in IEC 60825-1, IEC 60825-2 and IEC 60050(845).

3.1
angular subtense
the visual angle α subtended by the *apparent source* (including diffuse reflections) at the eye of an observer or at the point of measurement. The angular subtense is measured from the apparent source at either the distance of intended use or, at the distance of the expected exposure, whichever is applicable. This distance must not be smaller than 100 mm

NOTE The requirements for the determination of the angular subtense are given in 6.2.2 and 6.3.

3.2
apparent source
the real or virtual object that forms the smallest possible retinal image

NOTE The size of the apparent source is the parameter that defines the limits of an *intermediate source.*

3.3
application types
this technical specification distinguishes two types of applications for *diode emitter (DE) products* with *peak wavelengths* within the range 400 nm to 700 nm:

type 1: for *DE products* which are safe under *reasonably foreseeable* conditions of operation for *intended viewers* and personnel in service and manufacturing;

type 2: for *DE products* which are safe under *reasonably foreseeable* conditions of operation for *intended viewers* only. Protective measures for service and manufacturing, in accordance with IEC 60825-1, clause 10 and subclauses 12.2, 12.4, 12.6.3, are obligatory.

NOTE The terminology reflects the safety classification philosophy of the basic standard (class 1: always safe, class 2: safety under realistic viewing conditions, e.g. aversion reactions), in that increasing hazard is denoted by increasing numerical category.

3.4
CIE standard photometric observer
ideal observer having a relative spectral responsivity curve that conforms to the $V(\lambda)$ function for photopic vision or to the $V'(\lambda)$ function for scotopic vision, and that complies with the summation law implied in the definition of *luminous flux*

3.5
diode emitter (DE)
any semiconductor pn junction device that can be made to produce optical, electromagnetic radiation by radiative recombination of excited carriers

NOTE The following designations for diode emitters are commonly used:

LED (Light Emitting Diode) emitting in the wavelength range from 380 nm to 780 nm. In this technical specification LEDs are limited to peak wavelengths between 400 nm and 700 nm. In some cases (IEC 60825-1) the term LED is used for all diode emitters except LDs.

IRED (Infra-Red Emitting Diode) emitting in the wavelength range from 780 nm to 1 mm (not covered by this technical specification).

LD (Laser Diode) emitting stimulated radiation at any wavelength.

In this technical specification, the term Diode Emitter (DE) is used for both LEDs and LDs.

3.6
DE product
any product where the primary intent is to emit visible light which originates from a *diode emitter* source forming part of the product

3.7
embedded DE product
in this technical specification a DE *product* which, because of engineering features limiting the accessible emissions, has been assigned in a class or *application type* number lower than the inherent capability of the incorporated DE

3.8
intended viewer
a person looking at a visible source (display), who may lack a knowledge of the product or the technology involved, and typically without relevant safety training

3.9
intermediate source viewing
the viewing conditions whereby the *apparent source*, at a distance of 100 mm or more, subtends an angle at the eye greater than the *minimum angular subtense* (α_{min}) but smaller than the *maximum angular subtense* (α_{max})

NOTE In contrast to *small sources* and *large sources*, the retinal thermal hazard to the eye caused by intermediate sources depends significantly on the size of the retinal image. Optical devices (which are to be considered for inherently safe viewing conditions) may increase the hazard due to an increase in the power collected from the source and imaged by the eye onto the retina (see also 3.14).

3.10
irradiance (at a point on a surface)
the r*adiant flux* Φ_e incident on an element of a surface divided by the area dA of that element:

$$E = d\Phi_e / dA \quad \text{Unit: W/m}^2$$

3.11
large source viewing
the viewing conditions whereby the *apparent source* at a distance of 100 mm or more subtends an angle at the eye greater than the *maximum angular subtense* (α_{max})

NOTE For example viewing of diffusely reflected laser radiation from large expanded beams, or from some laser and LED arrays.

3.12
luminous flux
quantity derived from *radiant flux* Φ_e by evaluating the radiation according to its action upon the *CIE standard photometric observer*. For photopic vision:

$$\Phi_v = 683 \text{ lm/W} \int d\Phi_e(\lambda)/d\lambda \times V(\lambda) d\lambda$$

where

$d\Phi_e(\lambda)/d\lambda$ is the spectral distribution of the *radiant flux;*

$V(\lambda)$ is the spectral luminous efficiency.

For scotopic vision $\Phi_{v'}$ is calculated using the previous formula replacing 683 lm/W and $V(\lambda)$ by 1 700 lm/W and $V'(\lambda)$ respectively. Unit: lm (lumen)

3.13
luminous intensity (of a source, in a given direction)
quotient of the fraction of *luminous flux* $d\Phi_v$, leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle: $I_v = d\Phi_v/d\Omega$. Unit: cd (candela: lm/sr)

3.14
magnification (*M*)
The angular magnification *M* of an optical instrument is the ratio of the visual angles subtended (*angular subtense*) by the object with and without the instrument

NOTE Optical devices (which are to be considered for inherently safe viewing conditions) between the source and the eye may therefore increase the hazard due to increased power collection of the source, imaged onto the retina. The value of the magnification can influence the hazard aspects of the different viewing conditions (see 3.9, 3.11, 3.25).

3.15
maximum angular subtense (α_{max})
the value of *angular subtense* of the *apparent source* above which a source is considered to be a *large source*

3.16
maximum permissible exposure (*MPE*)
a value of exposure to the eye or skin which, under normal circumstances, is not expected to result in adverse biological effects. The MPE levels represent the maximum level to which the eye or the skin can be exposed without consequential injury under acute or chronic conditions. They are related to the wavelength of the radiation, the exposure duration, the tissue at risk and the size of the retinal image (*apparent source* size). Maximum permissible exposure levels, expressed in *irradiance* or *radiant exposure*, are specified in IEC 60825-1, clause 13.

3.17
minimum angular subtense (α_{min})
the value of *angular subtense* of the *apparent source* above which a source is considered an *intermediate* or *large source*

3.18
nominal ocular hazard distance (*NOHD*)
the maximum distance from the source where the *irradiance* finally falls below the appropriate *MPE* (see 6.5)

3.19
peak wavelength
wavelength at the maximum of the spectral distribution of the *DE*s

NOTE In contrast to monochromatic laser radiation, the spectral radiation bandwidth of LEDs amounts to some 10 nanometers and is neither monochromatic nor broadband. However, the wavelength band of LEDs can be described by stating a single wavelength – the peak wavelength – because the *MPE* does not vary significantly within this wavelength band.

For calculating *MPE* values from the tables in IEC 60825-1, either the peak wavelength of *DE*s can be used or alternatively the wavelength dependence of factor C_4 can be taken into account.

3.20
reasonably foreseeable event
an event the occurrence of which under given circumstances can be predicted fairly accurately, and the occurrence probability or frequency of which is not low.

NOTE Examples of reasonably foreseeable events might include operator error or inattention to safe working practices. Reckless use or use for completely inappropriate purposes is not to be considered as a reasonably foreseeable event.

3.21
radiant flux
power, emitted, transferred or received in the form of radiation. Symbol Φ_e; Unit: W.

3.22
radiant energy
time integral of the *radiant flux* over a given duration Δt: $Q = \int \Phi_e \, dt$. Unit: J

3.23
radiant exposure (at a point on a surface)
the *radiant energy Q* incident on an element of a surface divided by the area d*A* of that element:

$$H = \mathrm{d}Q/\mathrm{d}A = \int E\,\mathrm{d}t. \quad \text{Unit: J/m}^2$$

3.24
radiant intensity (of a source, in a given direction)
quotient of the of *radiant flux* dΦ_e leaving the source and propagated in the element of solid angle dΩ containing the given direction, by the element of solid angle:

$$I_e = \mathrm{d}\Phi_e/\mathrm{d}\Omega. \quad \text{Unit: W/sr}$$

3.25
small source viewing
the viewing conditions whereby the *apparent source*, at a distance of 100 mm or more, subtends an angle at the eye smaller than the *minimum angular subtense* (α_{min}).

NOTE For example intrabeam viewing of parallel collimated laser beams.

4 Manufacturing requirements

It is the responsibility of the manufacturer of *DE products*, or his agent, to determine the category of the application (type 1 or type 2), according to 6.4.1, 6.4.2 or 6.7. The type, the name and the publication date of the standard to which the product was categorized shall be documented in the operating manual.

Type 2 applications are safe to intended viewers under all *reasonably foreseeable* conditions because the product will be installed and operated at a distance from the *intended viewer* which is much larger than the *NOHD*. For personnel in manufacturing, maintenance and service additional safety measures, including the *NOHD*, have to be documented in the operating manual. The instructions shall also include legible reproductions of required labels and hazard warnings.

5 Labelling

5.1 General

Products shall carry label(s) in accordance with the requirements of the following subclauses. Labels shall be permanently fixed, legible, and clearly visible during maintenance or service, according to their purpose. They shall be so positioned that they can be read without the necessity for human exposure to optical radiation, during manufacturing and maintenance, in excess of the *MPE*. Text and borders shall be black on a white background. The label size should be adapted to the size of the product and must be legible at distance *NOHD*, see 6.5. Any labels shall be included in the operation manual.

5.2 Type 1 applications

Products for type 1 applications are exempted from labelling.

5.3 Type 2 applications

Products for type 2 applications shall bear the following label:

Caution Do not view directly at a distance smaller than the nominal ocular hazard distance of XXX mm. Do not view with optical instruments

This label shall be clearly legible at a distance greater than or equal to XXX mm.

NOTE XXX = NOHD, the minimum safe viewing distance to be determined by the manufacturer.

If the size or design of the product makes labelling impractical, the label shall be included with the user information or on the package and also with the service information, if present.

6 Tests and measurements for categorization and labelling

6.1 General

Measurement of radiation may be necessary to categorize a *DE product*. Measurements are unnecessary if the physical characteristics and limitations of the *DE* clearly place the *DE product* into a particular *application type*. In circumstances where direct measurements are impractical, categorization into *application types* shall be based on the manufacturer's design calculations.

Measurements shall be carried out according to 6.4. In the case of type 2 categorization, each and every *reasonably foreseeable* single fault condition shall be considered (see note).

Tests of products for type 1 applications, as long as they do not contain an *embedded device* greater than class 3A, are exempted from single fault considerations.

NOTE The worst case approach of type 1 test conditions are chosen to ensure that the MPE values cannot be exceeded under reasonably realistic viewing conditions and exposure durations. This is especially valid for surface emitting LEDs.

6.2 Determination of the apparent source size

6.2.1 General

Optical sources used for transmission of visible information to the human eye via displays, signs, signals and indicators are usually arrangements of single or multiple *DE*s.

Viewed at normal or minimal accommodation distance, the single *diode emitters* are distinguishable and considered as small or intermediate sources. If the angular separation between single emitters under these viewing conditions is larger than α_{max} the possible hazard of the whole arrangement is given by the *MPE* of one single emitter. For angular separation less than α_{max}, the most restrictive *MPE* resulting from each individual source and possible grouping, according to 13.4.2 of IEC 60825-1, shall be determined (see also IEC 60825-1, annex A: Example A.2-4).

Sometimes an array may be covered by scattering materials, and represent a "homogeneous luminescent field". This can subtend an angle (*angular subtense*) greater than α_{max} (100 mrad) with *large source* characteristics. In these cases the *small source*-*MPE*s may be increased according to 13.5 of IEC 60825-1, by the correction factor: $C_6 = \alpha_{max}/\alpha_{min}$.

Following the definition in IEC 60825-1, the beam dimension at the point of the smallest area containing 63 % of the total output power (or energy) shall be used for determination of the *apparent source size*. In the case of plastic encapsulated LEDs, including built-in lenses, reflectors and scattering materials, the *apparent source size* due to *magnification* of the optics as viewed from the direction of maximum *luminous intensity* shall be determined.

6.2.2 Measurement of the dimension of the apparent source

If the dimensions of the source are not known and the source is not accessible for measurements, the source has to be imaged by, for example, a lens. The lens shall have a diameter sufficient to intercept the majority beam power emitted by the source. The dimensions of the image of the source have to be determined according to the definition of the *apparent source* as follows:

a) For source images with circular symmetry a detector shall be used with a circular aperture in front of it. Both the detector and the aperture shall be larger than the image of the source to be measured. This assembly is placed in the plane of the image of the source, centred on the optical axis of the propagating beam, and the incident total power is measured.

b) The diameter of the aperture is reduced until the power passing through the aperture is equal to 63 % of the incident total power. The dimension of the aperture at this point gives the dimension D' of the beam in this plane.

c) For rectangular and oblong sources in place of the circular aperture a rectangular aperture has to be used.

d) With apparent source distance g and image distance b from the lens, the dimension D of the apparent source may be determined by the relation:

$$D = D' \times g/b.$$

When the radiator distance is not known, or the *apparent source* does not coincide with the radiation source (e.g. when the radiator contains lenses or reflectors), the distance g can be determined by the following formula:

$$g = 1/(1/f - 1/b),$$

where f is the focal length of the lens used to image the source.

Alternatively, a CCD camera system can be used to obtain the *apparent source* size from the power/energy density distribution on the detector. This is recommended if the shape of the source is not circular or rectangular.

6.3 Determination of the angular subtense

The *angular subtense* of a source is defined by the equation:

$$\alpha = 2 \arctan D/2r \cong D/r$$

where D is the source size and r the distance from the source to the viewer or measurement aperture. D is represented by the real or *apparent source size* (see 6.2) and r the applied viewing or measurement distance (see 6.4) respectively.

For circular or squared sources the value of the *angular subtense* is determined by the angular subtense of the diameter or the lateral length respectively. The value of the angular subtense of a rectangular or linear source is determined by the arithmetic mean of the two angular dimensions. Any angular dimension that is greater than α_{max} or less than 1,5 mrad should be limited to α_{max} or 1,5 mrad respectively, before determining the mean.

6.4 Measurements of optical radiation

Measurement of *irradiance* E [W/m^2] or *radiant exposure* H [J/m^2] shall be averaged over a circular limiting aperture with diameters d and at a distance r from the *apparent source*, according to the following requirements.

6.4.1 Measurement conditions for type 1 application

Diameter of measurement aperture: d = 7 mm.

Measurement distance of the limiting aperture: r = 100 mm.

In cases where, by virtue of engineering design, the measurement aperture cannot be placed at a distance *r* (e.g. recessed source), the minimum measurement distance shall be at the closest point of human access.

The *MPE* shall be evaluated on a time basis: t = 100 s,
if long-term intentional viewing is not inherent in the design or function of the source. Otherwise use the appropriate time basis up to 30 000 s.

6.4.2 Measurement conditions for type 2 application

Measurement condition 1: diameter of measurement aperture: d = 7 mm.

Measurement condition 2: the aperture diameter can be adapted to the general illumination of the place of intended use. It can be chosen to be equivalent to the corresponding pupil diameter of the eye. The pupil diameter d_P (in mm) may be calculated from the mean luminance L (in cd/m^2) of the object looked at or of the general illumination of the place of intended use by the following formula:

$$d_P = a + b / (1 + (L/c)^d)$$

with: a = 1,29; b = 6,62; c = 8,24; d = 0,32

The applicable measurement aperture can be adjusted correspondingly. If the illumination conditions vary, the aperture stop diameter corresponding to the lowest illumination shall be chosen.

The adjustment of the *MPE* values of IEC 60825-1 is proportional to the area of the pupil: $\mathrm{MPE}(d_P) = \mathrm{MPE}(7\ \mathrm{mm}) \times (7/d_P)^2$

NOTE The *MPE* values of IEC 60825-1 are based on the maximum pupil diameter of 7 mm. This value corresponds to very poor illumination conditions where the luminance is low. With increasing luminance the diameter of the pupil decreases below 7 mm, following the above formula. (In other optical radiation safety standards, the limits are based on smaller fixed pupil diameters between 2 mm and 3 mm). However, since the pupil diameter varies greatly across the population (and particularly with the use of drugs) the type 2 categorization requires, in the first order (measurement condition 1) a 7 mm aperture. The use of the actual illumination conditions could lead to a loss of safety margin and therefore should only be taken into account if an additional safety margin exists simultaneously (e.g. due to worst case assumptions of distance, time basis or source size).

The minimum distance at which *intended viewer* access is possible and expected under *reasonably foreseeable* conditions shall be chosen as the measurement distance. In the absence of other limitations, the following distances may be used for guidance: 100 mm as minimum accommodation distance (worst case); 250 mm as normal viewing distance (near point). The evaluation of the *MPE*s shall be based upon the expected exposure duration but shall not exceed 30 000 s.

For guidance the following time base might be used: 100 s for occasional and unintended viewing.

6.5 Nominal ocular hazard distance

In the far-field (where the size of the source is small compared to the distance) the basic inverse-square-law of radiometry and photometry may be used to determine the *NOHD* by the following formula:

$$NOHD = \sqrt{\frac{I_e}{MPE}} \quad \text{in m}$$

If the *MPE* is expressed in W/m² the *radiant intensity* I_e shall be expressed in W/sr.

If the *MPE* is expressed in J/m² the integrated *radiant intensity* I_e shall be expressed in J/sr.

NOTE The formula is valid only if the solid angle determined by the beam divergence is larger than the solid angle over which the power or energy is averaged. For example, the formula is not valid for collimated beams.

6.6 Repetitively pulsed, modulated or scanned radiation

The *MPE* values shall be determined by using the most restrictive requirement of IEC 60825-1, clause 13.

NOTE (see also IEC 60825-1, annex A, example A.2-4). For frequencies greater than the following limits, the most restrictive requirement is given by the average power assessment.

For wavelengths between 400 nm and 550 nm, when the pulse duration is in the range from 10^{-9} s to 1.8×10^{-5} s and the exposure time is in the range of 1.8×10^{-5} s to 10 s, the value of the limit is 55 174 Hz.

For wavelengths between 550 nm and 700 nm, when the pulse duration is in the range from 10^{-9} s to 1.8×10^{-5} s and the exposure time is in the range of 1.8×10^{-5} s to T_2 (see "Notes to tables 1 to 4"), the limit value is 55174 Hz.

For exposures longer than 0,7 s, the limits are valid only for angular subtenses not greater than 1,5 mrad. For greater *angular subtenses*, the limits can be at lower frequencies. For exposures shorter than 0,7 s, the limits are valid for all *angular subtenses.*

6.7 Simplified categorization procedure

If the *luminous intensity* of sources (in candela) is known, the following simplified categorization procedure is recommended:

- determination or provision (from data sheet) of the actual *luminous intensity* and *peak wavelength*;
- determination or provision (from manufacturer, or according to 6.3) of the *apparent source size*;
- comparison against the worst case *MPE*-related limits of *luminous intensity* in figure 1;
- if these limits are not exceeded, then categorize as type 1 and provide documentation according to clause 4.

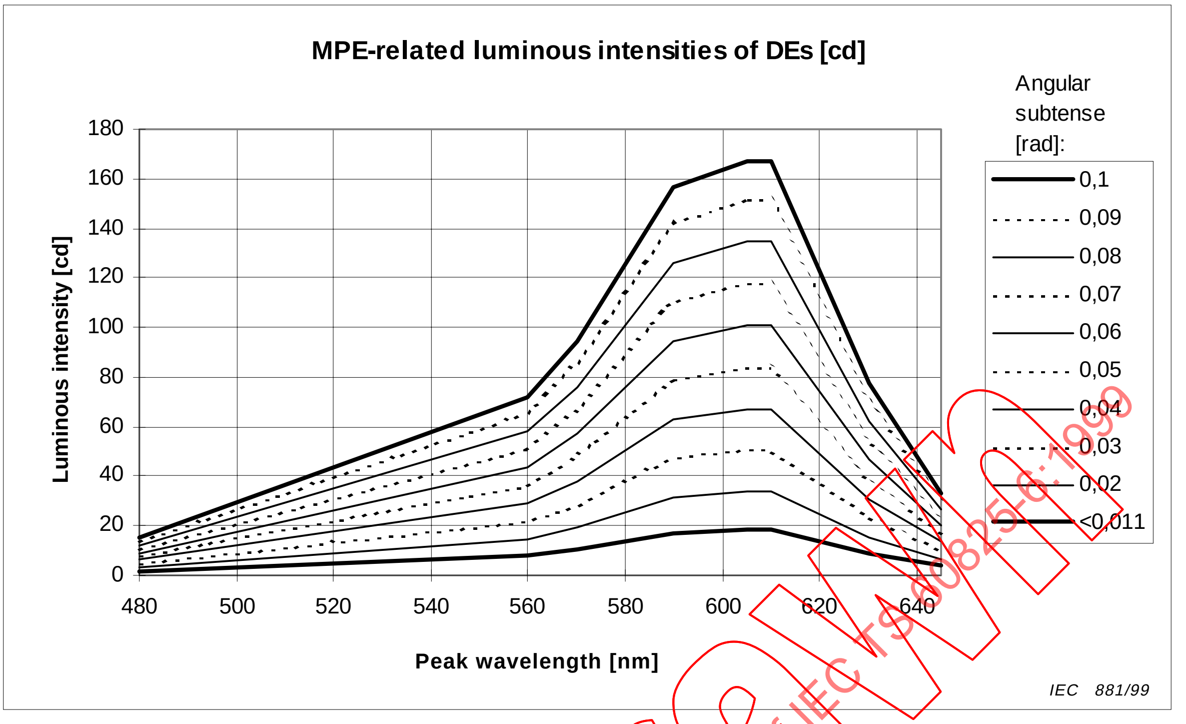


Figure 1 – *MPE*-related maximum allowable luminous intensities of visible *DE*s in type 1

NOTE The type 1 (see 6.4.1) related allowable *luminous intensities* of *DE*s with different *angular subtense* in figure 1 are calculated in the following way:

- time base: 100 s (occasional intended viewing);
- viewing distance: 100 mm (minimum accommodation distance);
- radiation geometry characterized by worst case Lambertian model;
- conversion to photometric units by measured lm/W values of typical LEDs.

Details about the conversion of the *MPE*-limits into *luminous intensity* limits of LEDs are provided in annex B.

Annex A
(informative)

Rationale

The safety of laser products, equipment classification, requirements and user’s guide are covered by IEC 60825-1. Laser radiation differs significantly from that of other sources due to the unique feature of coherency and the extreme narrow spatial and spectral distribution. Intrabeam viewing of collimated parallel laser beams leads to concentration of the whole of the radiation in a small spot on the viewers retina. Similarly, due to the extremely small dimensions of fibres or the active area of laser diode chips the retinal image may be a diffraction limited point. IEC 60825-1 and IEC 60825-2 mainly cover the (new) hazard aspects for the eye from these point sources. In this context extended source viewing originally meant viewing of diffusely reflected laser beam spots (e.g. on a laboratory wall).

Because of the increased radiated power available from LEDs and their physical similarity to laser diodes, they have been included in the scope of IEC 60825-1. However, the optical radiation of LEDs differs in various aspects from laser sources:

– the spectral radiation bandwidth of some 10 nanometers is neither monochromatic nor broadband with peak wavelengths in visible and near infrared;
– the spatial distribution of the emitted radiation ranges from Lambertian characteristics up to a nearly concentrated beam with any other variation in between, largely dependent on the package (built-in lenses, reflectors, scattering materials, etc.);
– the area of emission, the virtual source size, in most cases is determined by the package and mainly acts as an intermediate source compared to the measurement (minimum viewing) distance;
– for characterization of laser radiation the model of a Gaussian beam is commonly used; in the case of LEDs, modified Lambertian source models are preferred.

Related to optical radiation safety, the (new) intermediate emitters are divided into two groups, due to differences in possible safety mechanisms: "visible" (LEDs) for displays and indication purposes and "invisible" (IREDs).

The specific requirements for IREDs, operating in the near infrared spectral range and used for invisible free air-transmission of signals (remote control) or data, will be covered in IEC 60825-7.

In particular, "visible" LEDs are increasingly being used as a replacement for incandescent or fluorescent light sources. The advantages presented by LEDs over conventional lamps lead to growing applications for outdoor signs and signals (pedestrian and traffic signals, message signs) and automotive signal lighting (brake, indicator and rear lights, instrument clusters and displays). The advantages include:

– energy efficiency (power consumption ≤20 % of incandescent lamps);
– reliability/durability (insensitive to vibration and shock);
– appearance (styling to every shape);
– quick turn-on time (advantage for stop lights).

Most of these applications are also covered by standards that require minimum optical radiation intensities, for contrast and visibility, under various environmental conditions which have to be considered as safety standards as well (e.g. USA: FMVSS 108 "Federal Motor Vehicle Safety Standard"). Formal application of IEC 60825-1 for viewer's safety may therefore lead to conflicts with other safety standards.

In contrast to many other applications of point sources or invisible sources, visible sources used for displays, indicators, signs and signals are made for intentional viewing (intrabeam viewing is a prerequisite). Therefore, the current philosophy of IEC 60825-1 (i.e. 13.1: "..In any case, exposure to laser radiation shall be as low as possible.."), with its classification scheme and warning labels, cannot be fully applied to this type of emitter. As for viewing other (artificial or natural) bright sources, a degree of protection is afforded by natural aversion responses like the blink reflex and pupil contraction. When taking these effects into account for the "reasonably foreseeable conditions of use" of the class 1 definition in IEC 60825-1, the manufacturer and installer must guarantee that the source will never exceed the MPE at the minimum distance at which access by users is possible.

In most cases the optoelectronic signs and signals (e.g. highway or commercial message signs, traffic signals, etc.) are placed relatively far from the viewer to ensure the message is seen. The optical power levels required to obtain an acceptable recognition may (must) therefore particularly exceed the MPE at minimum viewing distance according to IEC 60825-1. The main parameter in this area is the luminous intensity of the signal lamps, because it is connected by the inverse square law with the threshold irradiance for the viewers' recognition with respect to the possible maximum viewing distance. The luminous intensity requirements for example for green traffic lights (about 300 cd) are derived for a visibility up to 75 m to 125 m. At the minimum accommodation distance of 0,1 m, the irradiance exceeds the MPE of 7 625 lx. Due to the inverse square law however, the irradiance strongly decreases with increasing distance. At 0,2 m the irradiance is therefore already below the MPE value and is far below any hazardous limit at the intentional viewer position. Nevertheless, in the case of manufacturing, maintenance and service, the MPE values may be exceeded and protection measures such as safety training and adequate eye protection have to be applied. Therefore, the applications for products covered in this part 6 are divided into two types:

type 1: safe for intended viewers and personnel in service and manufacturing;

type 2: safe for intended viewers but protection measures for personnel in service.

If the MPE limits are exceeded under these type 2-conditions, the product is excluded from the requirements of this part 6 and must be treated by the regulations of the basic standard. As there are no substantial differences in the biological damage caused by incoherent (LED) or coherent (Laser) radiation, at the present state of knowledge, the scope of part 6 must be strictly application-specific, rather than related to the nature of the source. In the case of the type 1-limits, the visible sources, if they do not contain an embedded device greater than Class 3A, additionally are exempted from the single fault consideration. In order to simplify the classification procedure, the MPEs were transformed (see annex B) into radiation limits (based on worst case assumptions) to be comparable with data available from data sheets. In practical cases, a brief examination of the supplied figures of the luminous intensity limits in part 6 may help to decide if additional actions (e.g. measurements) are necessary or not. The widely used visible status indicator LEDs (on monitors or battery chargers, etc.) may be checked in this way and do not need to be classified under single fault conditions as required by the basic standard.

Generally, the stress of the eyes by optical radiation when viewing displays, signs, indicators and signals is, in reality, limited by different factors:

Such sources are usually designed for information recognition without glare. The duration of direct observation is not greater than necessary for information recognition. This is particularly valid for LED (status) indicators. Only displays of measurement instruments or computer terminals for example are observed for longer periods of time from a close distance. Generally, the brightness of such terminals is adjustable and is chosen for proper and comfortable observation without eye fatigue.

In all cases the eye will adapt to the illumination conditions:

Pupil contraction may change the optical power entering the eye by a proportion of about 1:16 within about 0,2 s. Due to switching mechanisms in the human optical nerve system, the eye is furthermore capable of adapting to brightness in relation of about $1:10^{11}$. Unpleasant bright eye illumination will be avoided within similar duration by aversion reactions or blink reflex.

During normal work like data entry, text editing, dialogue, the real eye contact with the screen amounts to only a small percentage of the whole session time (which is also only a part of the working day).

Long-term fixation, attention and concentration is limited by eye fatigue. Due to micro-movements (drift and saccades) the picture is continuously scanned over the receptors inside the fovea with steady image information to the brain. As a result there is no constant point of fixation but an irregularly shaped "fixation field". This effect was already partially taken into account and included in the determination of the MPEs, but it also limits the possible steady fixation duration by eye fatigue (vigilance). Reading (e.g. a message on a display) leads furthermore to a "staircase" pattern of eye movements consisting of alternating saccades and periods of fixation. (Semantic identification is assumed to occur during the breaks.) Due to this averaging "scanning over alternately on- and off-switched screen dots" the retinal stress is additionally reduced.

Annex B
(informative)

Conversion of the maximum permissible exposure (MPE) limits into luminous intensities of LEDs

The measurement conditions in IEC 60825-1 represent a cone filled with a MPE-related partial flux. This can be transferred into a corresponding allowable radiant intensity if the spatial distribution characteristic of the source is known. For characterization of the radiation geometry of LEDs, the model of a modified Lambertian source is commonly used. For nearly all theoretical investigations this cosine approach of LED spatial distributions is sufficiently close to the measured distributions. Compared to the homogene radiance in all directions of a Lambertian source, most of the narrower beam profiles of LEDs may be represented by a raised cosine function:

$$I(\phi) = I_0 \cos^m \phi$$

where

I_0 is the on-axis intensity;

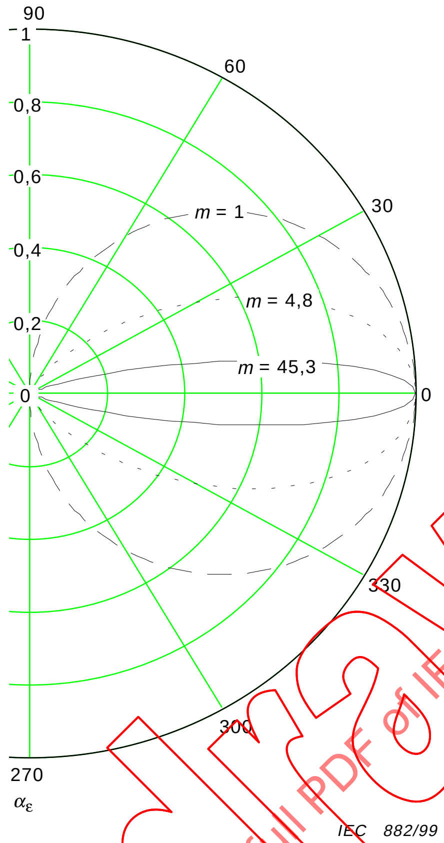
ϕ is the angle considered;

m is the modification parameter of the ideal (m = 1) cosine distribution;

m depends on the angle γ_{HW} which indicates the decrease of I to $I/2$ (LED data sheet):

$$m = \log 0{,}5/\log(\cos\gamma_{HW})$$

For examples see figure B.1.



key

m = 1 (ideal Lambertian source),

m = 4,8 for γ_{HW} = 30°

m = 45,3 for 10° half intensity angle

Figure B.1 – Examples of modified cosine distributions

In IEC 60825-1 the MPEs are given in irradiance (in W/m^2) or radiant exposure (in J/m^2). These values have to be measured by using apertures with a diameter of 7 mm in a distance of 100 mm, representing a measurement cone with the cone angle θ (= 0,035 sr, see figure B.2).

The partial flux $\Delta\Phi$ of a spatial cosine distribution inside the solid angle represented by θ amounts to:

$$\Delta\Phi(\theta) = I_0 2\pi(1 - \cos^{m+1}\theta)/(m+1)$$

With $\Delta\Phi(\theta)$ = MPE $\times$ C_6 $\times$ 3,85 $\times$ 10^{-5} as the allowable radiant power (in W) according to IEC 60825-1 for the appropriate wavelength and exposure duration, the corresponding allowable maximum radiant intensity amounts to:

$$I_{MPE} = \text{MPE} \times C_6 \times 3{,}85 \times 10^{-5}\,(m + 1) / 2\pi(1 - \cos^{m+1}(0{,}035)) \quad [\text{W/sr}]$$

For the conversion into photometrical quantities, the appropriate (measured) lm/W values must be applied.

By the above formula for the same MPE, the radiant intensity of a narrow beam emitting LED can be higher than for a LED with a rather broad spatial distribution. This is also schematically shown in figure B.2.