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IEC 60825-1

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Amendment 2

Safety of laser products –

Part 1:
Equipment classification, requirements and user's guide

Amendement 2

Sécurité des appareils à laser –

Partie 1:
Classification des matériels, prescriptions et guide de l'utilisateur

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FOREWORD

This amendment has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

The text of this amendment is based on the following documents:

FDIS	Report on voting
76/220/FDIS	76/223/RVD

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

The committee has decided that the contents of the base publication and its amendments will remain unchanged until 2003. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition; or
- amended.

A consolidated edition incorporating IEC 60825-1 (1993), amendment 1 (1997) and the present amendment 2 (2001) is under preparation.

The contents of the corrigendum of June 2002 have been included in this copy.

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1 Scope and object

1.1 Scope

At the end of the third paragraph, add the following sentence:

See also annex G which describes information which should be provided by manufacturers of LEDs.

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3 Definitions

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Replace, in definition 3.5, the reference in brackets by "3.7".

Add the following new definition:

3.6
angle of acceptance
plane angle within which a detector will respond to optical radiation, usually measured in radians. This angle of acceptance may be controlled by apertures or optical elements in front of the detector (see figure 16). The angle of acceptance is also sometimes referred to as the field of view

Symbol: γ

NOTE Angle of acceptance for evaluating photochemical hazards. For evaluation of the photochemical hazard, a limiting measurement angle of acceptance, γ_p, is specified. The angle γ_p is biologically related to eye movements and is not dependent upon the angular subtense of the source. If the angular subtense of the source is smaller than the limiting angle of acceptance, the actual measurement angle of acceptance does not have to be limited. If the angular subtense of the source is larger than the specified limiting angle of acceptance, the angle of acceptance has to be limited and the source has to be scanned for hotspots. If the measurement angle of acceptance is not limited to the specified level, the hazard may be over-estimated.

Symbol: γ_p

Replace the existing definition 3.6 as follows:

3.7
angular subtense (α)
angle subtended by an apparent source as viewed at a point in space. In this standard, for classification, the angular subtense is determined at a point not less than 100 mm from the apparent source (or at the exit window or lens of the product if the apparent source is located at a distance greater than 100 mm within the window or lens). (See also 3.53 and 3.57.) For an analysis of the maximum permissible exposure levels, the angular subtense shall be determined at the viewing distance from the apparent source but not less than 100 mm. This concept is also discussed in clause A.3 of annex A

NOTE 1 The angular subtense of an apparent source is applicable in this part 1 only in the wavelength range from 400 nm to 1 400 nm, the retinal hazard region.

NOTE 2 The angular subtense of the source should not be confused with the divergence of the beam.

Renumber definitions 3.7 and 3.8 to read 3.8 and 3.9. Add the following new definition 3.10 and renumber the definitions 3.9 to 3.15 to read 3.11 to 3.17:

3.10
beam
laser radiation that may be characterized by direction, divergence, diameter or scan specifications. Scattered radiation from a non-specular reflection is not considered to be a beam

3.13
beam divergence
In the second sentence, change "distance *L*" *into* "distance *r*".

Change the formula to read

$$\varphi = 2 \arctan\left(\frac{d_{63} - d'_{63}}{2r}\right)$$

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Replace definition 3.17 as follows:

3.17
Class 1 laser product
any laser product which does not permit human access to laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission durations (see 8.2 and 8.4e))

Add the following new definition 3.18:

3.18
Class 1M laser product
any laser product in the wavelength range from 302,5 nm to 4 000 nm which does not permit human access to laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission durations (see 8.4e)), where the level of radiation is measured according to 9.2g), however, evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 1 laser products. The output of a Class 1M product is therefore potentially hazardous when viewed using an optical instrument (see 8.2)

Replace definition 3.16 as follows:

3.19
Class 2 laser product
any laser product which does not permit human access to laser radiation in excess of the accessible emission limits of Class 2 for applicable wavelengths and emission durations (see 8.2 and 8.4e))

Add the following new definition 3.20 and renumber the definitions 3.17 to 3.57 to read 3.21 to 3.61:

3.20
Class 2M laser product
any laser product in the wavelength range from 400 nm to 700 nm which does not permit human access to laser radiation in excess of the accessible emission limits of Class 2 for applicable wavelengths and emission durations (see 8.4e)), where the level of radiation is measured according to 9.2h), however, evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 2 laser products. The output of a Class 2M product is therefore potentially hazardous when viewed using an optical instrument

In definitions 3.21 and 3.22 change "(see 9.2)" *to* "(see 8.2)".

Replace the title of definition 3.21 "Class 3A and Class 3B laser products" *by* "Class 3R and Class 3B laser products".

In the text of definition 3.21, change "3A" *to* "3R".

Add the following note at the end of definition 3.29:

NOTE The laser which is incorporated in the embedded laser product is called the embedded laser.

Add to definitions 3.30 and, on page 21, 3.32 the following second sentence:

For a train of pulses, this is the duration between the first half-peak power point of the leading pulse and the last half-peak power point of the trailing pulse

Add the following text at the end of definition 3.33:

Two extended source conditions are considered in this standard when considering retinal thermal injury hazards: intermediate source and large source, which are used to distinguish sources with angular subtenses, α, between α_{min} and α_{max} (intermediate sources), and greater than α_{max} (large sources). (See also 3.79.)

Replace, in definition 3.36a), third line, "Class 2, 3A or 3B of not more than 5 times the AEL of Class 2 in the wavelength region from 400 nm to 700 nm" *by* "Class 2, 2M or 3R".

Replace definition 3.38 as follows:

3.38
intrabeam viewing
all viewing conditions whereby the eye is exposed to the direct or specularly reflected laser beam in contrast to viewing of, for example, diffuse reflections

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Add the following new definition 3.62 after definition 3.61 and renumber definitions 3.58 to 3.73 to read 3.63 to 3.78:

3.62
photochemical hazard limit
either an MPE or AEL which was derived to protect persons against adverse photochemical effects (for example, photoretinitis – a photochemical retinal injury from exposure to radiation in the wavelength range from 400 nm to 600 nm)

Delete, in definition 3.69, at the end of the second line:

(usually expressed in $J \cdot m^{-2}$)

Add the following new definition 3.79 after definition 3.78 and renumber definitions 3.74 to read 3.80, and 3.75 to read 3.81:

3.79
small source
source with an angular subtense α less than, or equal to, the minimum angular subtense α_{min}

Add the following new definitions 3.82 and 3.83 after definition 3.81:

3.82
thermal hazard limit
either an MPE or AEL which was derived to protect persons against adverse thermal effects, as opposed to photochemical injury

3.83
time base
emission duration to be considered for classification (see 8.4 e))

Renumber definitions 3.76 to 3.80 to read 3.84 to 3.88

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4.3 Access panels and safety interlocks

Replace, in 4.3.1b) "the removal of the panel .... Class 2" *by* "the removal of the panel gives access to laser radiation levels designated by "X" in the table below."

Replace the table and the third paragraph by the following:

Product class	**Accessible emission during or after removal of access panel**				
	1, 1M	**2, 2M**	**3R**	**3B**	**4**
1, 1M	–	–	X	X	X
2, 2M	–	–	X	X	X
3R	–	–	–	X	X
3B	–	–	–	X	X
4	–	–	–	X	X

Removal of the panel shall not result in emission through the opening in excess of Class 1M or Class 2M as applicable according to the wavelength.

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4.4 Remote interlock connector

Replace the text of this subclause as follows:

Each Class 3B and Class 4 laser system shall have a remote interlock connector. When the terminals of the connector are open-circuited, the accessible radiation shall not exceed Class 1M or Class 2M as applicable.

4.5 Key control

Replace the first sentence as follows:

Each Class 3B and Class 4 laser system shall incorporate a key-operated master control.

4.6 Laser radiation emission warning

Subclause 4.6.1

Replace the first sentence by the following new first sentence:

Each Class 3R laser system in the wavelength range below 400 nm and above 700 nm and each Class 3B and Class 4 laser system shall give an audible or visible warning when it is switched on or if capacitor banks of a pulsed laser are being charged or have not positively discharged.

Replace, at the end of the last sentence, "in excess of the AEL for Class 1 and Class 2" *by* "in excess of the AEL for Class 1M and 2M".

4.7 Beam stop or attenuator

Replace the existing text by the following new text:

Each Class 3B and Class 4 laser system shall incorporate one or more permanently attached means of attenuation (beam stop or attenuator, other than a laser energy source switch, mains connector or key control). The beam stop or attenuator shall be capable of preventing human access to laser radiation in excess of Class 1M or Class 2M as applicable.

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4.8 Controls

Replace, at the end of the sentence, "do not require exposure to laser radiation in excess of the AEL for Class 1 and Class 2" *by* "do not require exposure to laser radiation of Class 3R, 3B or Class 4".

4.9 Viewing optics

Replace, "in excess of the AEL for Class 1" *by* "in excess of the AEL for Class 1M" (three times).

4.12 "Walk-in" access

Replace the existing texts in a) and b) by the following:

a) means shall be provided so that any person inside the housing can prevent activation of a Class 3B or Class 4 laser hazard.

b) a warning device shall be situated so as to provide adequate warning of emission of Class 3R laser radiation in the wavelength range below 400 nm and above 700 nm, or of Class 3B or Class 4 laser radiation to any person who might be within the housing.

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5.2 Class 1

Replace the existing text by the following:

Except as permitted in 1.1, each Class 1 laser product shall have affixed an explanatory label (figure 15) bearing the words:

CLASS 1 LASER PRODUCT

Each Class 1M laser product shall have affixed an explanatory label (figure 15) bearing the words:

LASER RADIATION
DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 1M LASER PRODUCT

The type of optical instrument which could result in an increased hazard may be added in parenthesis after the word "instruments". The added wording could in particular be "(BINOCULARS OR TELESCOPES)" for a laser product with a collimated, large-diameter beam, which is classified 1M because it fails condition 1 of table 10, or "(MAGNIFIERS)" for a laser product which is classified 1M because it fails condition 2 of table 10 (highly diverging beam).

Instead of the above labels, at the discretion of the manufacturer, the same statements may be included in the information for the user.

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5.3 Class 2

Add the following text:

Each Class 2M laser product shall have affixed a warning label (figure 14) and an explanatory label (figure 15) bearing the words:

LASER RADIATION
DO NOT STARE INTO THE BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 2M LASER PRODUCT

The type of optical instrument which could result in an increased hazard may be added in parenthesis after the word "instruments". The added wording could in particular be "(BINOCULARS OR TELESCOPES)" for a laser product with a collimated, large-diameter beam which is classified 2M because it fails condition 1 of table 10, or "(MAGNIFIERS)" for a laser product which is classified 2M because it fails condition 2 of table 10 (highly diverging beam).

5.4 Class 3A

Replace the title and text by the following:

5.4 Class 3R

Each Class 3R laser product in the wavelength range from 400 nm to 1 400 nm shall have affixed a warning label (figure 14) and an explanatory label (figure 15) bearing the words:

LASER RADIATION
AVOID DIRECT EYE EXPOSURE
CLASS 3R LASER PRODUCT

For other wavelengths, each Class 3R laser product shall have affixed a warning label (figure 14) and an explanatory label (figure 15) bearing the words:

LASER RADIATION
AVOID EXPOSURE TO BEAM
CLASS 3R LASER PRODUCT

5.7 Aperture label

Replace "Each Class 3B and Class 4…" *by* "Each Class 3R, Class 3B and Class 4…"

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5.8 Radiation output and standards information

Replace the existing text by the following:

Each laser product, except those of Class 1, shall be described on the explanatory label (figure 15) by a statement of the maximum output of laser radiation, the pulse duration (if appropriate) and the emitted wavelength(s). The name and publication date of the standard to which the product was classified shall be included on the explanatory label or elsewhere in close proximity on the product. For Class 1 and Class 1M, instead of the labels on the product, the information may be contained in the information for the user.

5.9.1 Labels for panels

Replace, at the end of the first sentence of the first paragraph "... shall have affixed a label bearing the words:" *by* "...shall have affixed labels bearing the words (for the case of an embedded Class 1M laser, the statement instead may be included in the information for the user):"

Replace the warnings in 5.9.1 as follows:

a)

CAUTION – CLASS 1M LASER RADIATION WHEN OPEN
DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS

if the accessible radiation does not exceed the AEL for Class 1M where the level of radiation is measured according to 9.2g) and 9.3;

b)

CAUTION – CLASS 2 LASER RADIATION WHEN OPEN
DO NOT STARE INTO THE BEAM

if the accessible radiation does not exceed the AEL for Class 2 where the level of radiation is measured according to 9.2h) and 9.3;

c)

CAUTION – CLASS 2M LASER RADIATION WHEN OPEN
DO NOT STARE INTO THE BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS

if the accessible radiation does not exceed the AEL for Class 2M where the level of radiation is measured according to 9.2h) and 9.3;

d)

CAUTION – CLASS 3R LASER RADIATION WHEN OPEN
AVOID DIRECT EYE EXPOSURE

if the accessible radiation is in the wavelength range from 400 nm to 1 400 nm and does not exceed the AEL for Class 3R;

e)

CAUTION – CLASS 3R LASER RADIATION WHEN OPEN
AVOID EXPOSURE TO THE BEAM

if the accessible radiation is outside the wavelength range from 400 nm to 1 400 nm and does not exceed the AEL for Class 3R;

f)

CAUTION – CLASS 3B LASER RADIATION WHEN OPEN
AVOID EXPOSURE TO THE BEAM

if the accessible radiation does not exceed the AEL for Class 3B;

g)

CAUTION – CLASS 4 LASER RADIATION WHEN OPEN
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION

if the accessible radiation exceeds the limits for Class 3B.

This information may be provided in more than one adjacent label on the product.

5.9.2 Labels for safety interlocked panels

Modify the last sentence of the first paragraph and the warning as follows, and delete the second paragraph:

Such labels shall be visible prior to and during interlock override and be in close proximity to the opening created by the removal of the protective housing. This label shall bear the words specified in items a) to g) of 5.9.1, with the introduction of an additional line, positioned after the first line, with the following words:

AND INTERLOCKS DEFEATED

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5.10 Warning for invisible laser radiation

Replace, in the first sentence, "... for explanatory labels includes the phrase" *by* "... for labels in clause 5 includes the phrase ...".

Add at the end of this subclause:

If a product is classified on the basis of the level of visible laser radiation and also emits in excess of the AEL of Class 1 at invisible wavelengths, the label shall include the words "Visible and invisible laser radiation" in lieu of "Laser radiation".

5.11 Warning for visible laser radiation

Replace, in the first sentence, "The wording "laser radiation" on the explanatory labels may be modified to read..." *by* "The wording "laser radiation" for labels in Clause 5 may be modified to read...".

6.1 Information for the user

Insert a new item at the end of 6.1a) and renumber subsequent original items to read 6.1c) to g) inclusive:

b) For Class 1M and 2M laser products an additional warning is required. For diverging beams, this warning shall state that viewing the laser output with certain optical instruments (for example, eye loupes, magnifiers and microscopes) within a distance of 100 mm may pose an eye hazard. For collimated beams, this warning shall state that viewing the laser output with certain optical instruments designed for use at a distance (for example, telescopes and binoculars) may pose an eye hazard.

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6.2 Purchasing and servicing information

Replace the text of item a) by the following:

a) In all catalogues, specification sheets and descriptive brochures, the classification of each laser product and any warnings required by 6.1b) shall be stated.

7.1 Medical laser products

Delete item b) and include item a) into the second sentence to read:

In addition, any Class 3B or Class 4 medical laser product shall comply with IEC 60601-2-22.

7.2 Laser fibre optic transmission system

Replace the title and text of this subclause as follows:

7.2 Other parts of the standard series IEC 60825

For specific applications, one or other of the following IEC 60825 series may be applicable (see also annex H).

- IEC 60825-2 is additionally applicable to optical fibre communication systems.
- IEC 60825-4 is additionally applicable to laser guards.
- Further information on laser shows may be found in IEC/TR 60825-3.
- Further information regarding a manufacturer's checklist may be found in IEC/TR 60825-5.
- Further information regarding products exclusively used for visible information transmission may be found in IEC/TS 60825-6.
- Further information regarding products exclusively used for non-visible information transmission may be found in IEC/TS 60825-7.
- Guidelines for the safe use of medical laser equipment may be found in IEC/TR 60825-8.
- Further information regarding a review of MPEs for incoherent radiation may be found in IEC/TR 60825-9.

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8 Tests

Replace the title and text of clause 8 by the following:

8 Classification

8.1 Introduction

Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of a laser beam, the hazards arising in its use vary widely. It is impossible to regard lasers as a single group to which common safety limits can apply.

8.2 Description of laser classes

Class 1: Lasers that are safe under reasonably foreseeable conditions of operation, including the use of optical instruments for intrabeam viewing.

Class 1M: Lasers emitting in the wavelength range from 302,5 nm to 4 000 nm which are safe under reasonably foreseeable conditions of operation, but may be hazardous if the user employs optics within the beam. Two conditions apply:

a) for diverging beams if the user places optical components within 100 mm from the source to concentrate (collimate) the beam; or

b) for a collimated beam with a diameter larger than the diameter specified in table 10 for the measurements of irradiance and radiant exposure.

Class 2: Lasers that emit visible radiation in the wavelength range from 400 nm to 700 nm where eye protection is normally afforded by aversion responses, including the blink reflex. This reaction may be expected to provide adequate protection under reasonably foreseeable conditions of operation including the use of optical instruments for intrabeam viewing.

NOTE Outside the wavelength range from 400 nm to 700 nm, any additional emissions of Class 2 lasers are required to be below the AEL of Class 1.

Class 2M: Lasers that emit visible radiation in the wavelength range from 400 nm to 700 nm where eye protection is normally afforded by aversion responses including the blink reflex. However, viewing of the output may be more hazardous if the user employs optics within the beam. Two conditions apply:

a) for diverging beams, if the user places optical components within 100 mm from the source to concentrate (collimate) the beam, or

b) for a collimated beam with a diameter larger than the diameter specified in table 10 for the measurements of irradiance and radiant exposure.

NOTE Outside the wavelength range from 400 nm to 700 nm, any additional emissions of Class 2M lasers are required to be below the AEL of Class 1M.

Class 3R: Lasers that emit in the wavelength range from 302,5 nm to 10^6 nm where direct intrabeam viewing is potentially hazardous but the risk is lower than for Class 3B lasers, and fewer manufacturing requirements and control measures for the user apply than for Class 3B lasers. The accessible emission limit is within five times the AEL of Class 2 in the wavelength range from 400 nm to 700 nm and within five times the AEL of Class 1 for other wavelengths.

Class 3B: Lasers that are normally hazardous when direct intrabeam exposure occurs (i.e. within the NOHD). Viewing diffuse reflections is normally safe (see also note to 12.5.2c)).

Class 4: Lasers that are also capable of producing hazardous diffuse reflections. They may cause skin injuries and could also constitute a fire hazard. Their use requires extreme caution.

8.3 Classification responsibilities

It is the responsibility of the manufacturer or his agent to provide correct classification of a laser product. The product shall be classified on the basis of that combination of output power(s) and wavelength(s) of the accessible laser radiation over the full range of capability during operation at any time after manufacture which results in its allocation to the highest appropriate class. The accessible emission limit (AELs) for Class 1 and 1M, Class 2 and 2M, Class 3R and Class 3B (listed in order of increasing hazard) are given in tables 1, 2, 3 and 4 respectively.

The values of the correction factors used are given in the notes to tables 1 to 4 as functions of wavelength, emission duration, number of pulses and angular subtense.

8.4 Classification rules

For the purpose of classification rules, the following ranking of the classes (in increasing order of hazard) shall be used: Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, Class 4.

NOTE For classification of a laser product as Class 1M or 2M, the use of an aperture, specified in table 10 for irradiance and radiant exposure at the distances in that table for these measurements, limits the amount of radiation that is collected from large diameter or highly diverging beams. For example, when measured under the applicable conditions, Class 1M and Class 2M products may have higher measured energy or power than the AEL of Class 3R. For such laser products, a classification of 1M or 2M is appropriate.

a) Radiation of a single wavelength

A single wavelength laser product, with a spectral range of the emission line narrow enough so that the AELs do not change, is assigned to a class when the accessible laser radiation, measured under the conditions appropriate to that class, exceeds the AEL of all lower classes but does not exceed that of the class assigned.

b) Radiation of multiple wavelengths

1) A laser product emitting two or more wavelengths in spectral regions shown as additive in table 5 is assigned to a class when the sum of the ratios of the accessible laser radiation, measured under the conditions appropriate to that class, to the AELs of those wavelengths is greater than unity for all lower classes but does not exceed unity for the class assigned.

2) A laser product emitting two or more wavelengths not shown as additive in table 5 is assigned to a class when the accessible laser radiation, measured under the conditions appropriate to that class, exceeds the AELs of all lower classes for at least one wavelength but does not exceed the AEL for the class assigned for any wavelength.

c) Radiation from extended sources

The ocular hazard from laser sources in the wavelength range from 400 nm to 1 400 nm is dependent upon the angular subtense of the source. A source is considered an extended source when the angular subtense of the source is greater than α_{min}, where α_{min} = 1,5 mrad. For retinal thermal hazard evaluation (400 nm to 1 400 nm), the AELs for extended sources vary directly with the angular subtense of the source. For the retinal photochemical hazard evaluation (400 nm to 600 nm), for exposures greater than 1 s, the AELs do not vary directly with the angular subtense of the source, but, depending on the exposure duration (see 9.3c) i), a limiting angle of acceptance γ_p of 11 mrad or more is used for measurement, and the relation of the limiting acceptance angle γ_p to the angular subtense α of the source can influence the measured value.

For sources subtending an angle less than or equal to α_{min}, the AEL and MPE are independent of the angular subtense of the source α.

For an extended source, the power or energy measured must be below the permitted power or energy for the AEL specified for the class as a function of the angular subtense of the source α.

For classifying laser products where condition 1 applies (see table 10), the angular subtense α of the apparent source shall be determined at the location of the 50 mm measurement aperture. The 7× magnification of the angular subtense α of the apparent source may be applied to determine C_6, i.e. $C_6 = 7 \times \alpha / \alpha_{min}$, provided that it can be demonstrated that the smallest possible retinal spot diameter will not be less than $C_6 \times 25$ µm when the radiation is viewed through an optical instrument of magnification 7. The expression $(7 \times \alpha)$ shall be limited to α_{max} prior to the calculation of C_6.

NOTE For the case that $\alpha < 1,5$ mrad but $7 \times \alpha > 1,5$ mrad, the limits for $\alpha > 1,5$ mrad of table 1 and 3 apply, provided that the 7× magnification of the retinal spot diameter can be demonstrated.

For classifying laser products where condition 2 applies (see table 10), the angular subtense α of the apparent source shall be determined at the nearest point of human access to the apparent source, but not less than 100 mm.

d) Non-circular and multiple sources

For laser radiation where the apparent source consists of multiple points or is a linear source with an angular subtense greater than α_{min} and within the wavelength range from 400 nm to 1 400 nm, measurements or evaluations shall be made for every single point, or assembly of points, necessary to assure that the source does not exceed the AEL for each possible angle α subtended by each partial area, where $\alpha_{min} \leq \alpha \leq \alpha_{max}$.

For the retinal photochemical hazard limits (400 nm to 600 nm), the limiting angle of acceptance γ_p to be used to evaluate extended sources is specified in 9.3 c) i).

For the determination of the AEL retinal thermal hazard limits (400 nm to 1 400 nm), the value of the angular subtense of a rectangular or linear source is determined by the arithmetic mean of the two angular dimensions of the source. Any angular dimension that is greater than α_{max} or less than α_{min} shall be limited to α_{max} or α_{min} respectively, prior to calculating the mean. The photochemical limits (400 nm to 600 nm) do not depend on the angular subtense of the source, and the source is measured with the angle of acceptance specified in 9.3 c).

e) Time bases

The following time bases are used in this standard for classification:

i) 0,25 s for Class 2, Class 2M and Class 3R laser radiation in the wavelength range from 400 nm to 700 nm.

ii) 100 s for laser radiation of all wavelengths greater than 400 nm except for the cases listed in i) and iii).

iii) 30 000 s for laser radiation of all wavelengths less than or equal to 400 nm and for laser radiation of wavelengths greater than 400 nm where intentional long-term viewing is inherent in the design or function of the laser product.

NOTE Every possible emission duration within the time base must be considered when determining the classification of a product. This means that the emission level of a single pulse must be compared to the AEL applicable to the emission duration of the pulse, etc. It is not sufficient to merely average the emission level for the duration of the classification time base.

f) Repetitively pulsed or modulated lasers

The following methods shall be used to determine the AEL to be applied to repetitive pulsed emissions.

The AEL for wavelengths from 400 nm to 10^6 nm is determined by using the most restrictive of requirements i), ii) and iii) as appropriate. For other wavelengths, the AEL is determined by using the most restrictive of requirements i) and ii). Requirement iii) applies only to the thermal limits, not to the photochemical limits.

i) The exposure from any single pulse within a pulse train shall not exceed the AEL for a single pulse.

ii) The average power for a pulse train of emission duration *T* shall not exceed the power corresponding to the AEL given in tables 1, 2, 3 and 4, respectively for a single pulse of emission duration *T*.

iii) The average pulse energy from pulses within a pulse train shall not exceed the AEL for a single pulse multiplied by the correction factor C_5. If pulses of variable amplitude are used, the assessment is made for pulses of each amplitude separately, and for the whole train of pulses.

$$AEL_{train} = AEL_{single} \times C_5$$

where

AEL_{train} is the AEL for any single pulse in the pulse train;

AEL_{single} is the AEL for a single pulse;

$C_5 = N^{-0,25}$;

N is the number of pulses in the pulse train during the duration according to the following:

Wavelength	Duration to determine *N*
400 nm to 1 400 nm	T_2 (see note 2 of the notes to tables 1 to 4) or the applicable time basis, whichever is shorter
>1 400 nm	10 s

C_5 is only applicable to individual pulse durations shorter than 0,25 s.

In some cases, the calculated value may fall below the AEL that would apply for continuous operation at the same peak power using the same time base. Under these circumstances, the AEL for continuous operation may be used.

If multiple pulses appear within the period of T_i (see table 9), they are counted as a single pulse to determine *N* and the energies of the individual pulses are added to be compared to the AEL of T_i, provided that all individual pulse durations are greater than 10^{-9} s.

NOTE The energy from any group of pulses (or sub-group of pulses in a train) delivered in any given time should not exceed the AEL for that time.

Table 9 – Times T_i below which pulse groups are summed up

Wavelength	T_i
400 nm ≤ λ < 1 050 nm	18×10^{-6} s
1 050 nm ≤ λ < 1 400 nm	50×10^{-6} s
1 400 nm ≤ λ < 1 500 nm	10^{-3} s
1 500 nm ≤ λ < 1 800 nm	10 s
1 800 nm ≤ λ < 2 600 nm	10^{-3} s
2 600 nm ≤ λ ≤ 10^6 nm	10^{-7} s

In cases of varying pulse widths or pulse intervals, the total-on-time-pulse (TOTP) method may be used in place of requirement iii). In this case, the AEL is determined by the duration of the TOTP, which is the sum of all pulse durations within the emission duration or T_2, whichever is smaller. Pulses with durations less than T_i, are assigned pulse durations of T_i. If two or more pulses occur within a duration of T_i, these pulse groups are assigned pulse durations of T_i. For comparison with the AEL for the corresponding duration, all individual pulse energies are added.

This method is equivalent to requirement iii) when the average energy of pulses is compared to the AEL of a single pulse multiplied with C_5.

IEC/TR 60825-9 presents an alternative procedure that may be considered.

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9 Classification

Replace the title and text of clause 9 by the following:

9 Measurements for classification

9.1 Tests

Tests shall take into account all errors and statistical uncertainties in the measurement process (see IEC 61040) and increases in emission and degradation in radiation safety with age. Specific user requirements may impose additional tests.

Tests during operation shall be used to determine the classification of the product. Tests during operation, maintenance and service shall also be used as appropriate to determine the requirements for safety interlocks, labels and information for the user. The above tests shall be made under each and every reasonably foreseeable single-fault condition; however, faults which result in the emission of radiation in excess of the AEL for a limited period only, and for which it is not reasonably foreseeable that human access to the radiation will occur before the product is taken out of service, need not be considered.

NOTE For example, surface-emitting LEDs will be a product group where the single-fault condition need not be considered. (Surface-emitting LEDs are conventional LEDs without gain where the emission is orthogonal to the chip surface, and the chip surface can be viewed directly. It may have a built-in lens or reflector.)

Equivalent tests or procedures are acceptable.

Optical amplifiers shall be classified using the maximum accessible total output power or energy, which may include maximum rated input power or energy.

NOTE In those cases where there is no clear output power or energy limit, the maximum power or energy added by the amplifier plus the necessary input signal power or energy to achieve that condition should be used.

9.2 Measurement of laser radiation

Measurement of laser radiation levels may be necessary to classify a laser product in accordance with 9.1. Measurements are unnecessary when the physical characteristics and limitations of the laser source place the laser product or laser installation clearly in a particular class. Measurements shall be made under the following conditions.

a) Under those conditions and procedures which maximize the accessible emission levels, including start-up, stabilized emission and shut-down of the laser product.

b) With all controls and settings listed in the operation, maintenance and service instructions adjusted in combination to result in the maximum accessible level of radiation. Measurements are also required with the use of accessories that may increase the radiation hazard (for example, collimating optics) and that are supplied or offered by the manufacturer for use with the product.

c) For a laser product other than a laser system, with the laser coupled to that type of laser energy source which is specified as compatible by the laser product manufacturer and which produces the maximum emission of accessible radiation from the product.

d) At points in space to which human access is possible during operation for measurement of accessible emission levels (for example, if operation may require removal of portions of the protective housing and defeat of safety interlocks, measurements shall be made at points accessible in that product configuration).

e) With the measuring instrument detector so positioned and so oriented with respect to the laser product as to result in the maximum detection of radiation by the instrument.

f) Appropriate provision shall be made to avoid or to eliminate the contribution of collateral radiation to the measurement.

g) Class 1 and 1M

   In the wavelength range of 302,5 nm to 4 000 nm, if the level of radiation, as determined according to table 10, for condition 1 and condition 2 is less than, or equal to, the AEL of Class 1, the laser product is assigned to Class 1.

   If the level of radiation, as determined according to table 10, is larger than the AEL of Class 1 for condition 1 or condition 2 and less than the AEL of Class 3B, but with an aperture stop of diameter and at a distance from the apparent source as specified in table 10 for irradiance or radiant exposure measurements is less than, or equal to, the AEL of Class 1, the laser product is assigned to Class 1M.

   NOTE To limit the maximum power passing through an optical instrument for Class 1M, the AELs of Class 3B are also employed with the measurement of power or energy.

h) Class 2 and 2M

   In the wavelength range of 400 nm to 700 nm, if the level of radiation, as determined according to table 10, for condition 1 and condition 2 exceeds the AEL of Class 1 and is less than or equal to the AEL of Class 2, the laser product is assigned to Class 2.

   If the level of radiation as determined according to table 10 is larger than the AEL of Class 2 for condition 1 or condition 2 and less than the AEL of Class 3B, but the level of radiation measured with an aperture stop of diameter and at a distance as specified in table 10 for irradiance or radiant exposure measurements is less than, or equal to, the AEL of Class 2, the laser product is assigned to Class 2M.

   NOTE To limit the maximum power passing through an optical instrument for Class 2M, the AELs of Class 3B are also employed with measurements of power or energy.

9.3 Measurement geometry

Two measurement conditions as given in table 10 apply for wavelengths where optically aided viewing may increase the hazard. The most restrictive condition shall be applied. If the applicability of condition 1 or 2 is not obvious, both cases shall be evaluated. Condition 1 applies to collimated beams where telescopes and binoculars may increase the hazard, and condition 2 applies to sources with a highly diverging output where the use of microscopes, hand magnifiers and eye loupes may increase the hazard.

For power and energy measurement of scanned laser radiation, the measurement apertures and distances as specified in table 10 for irradiance or radiant exposure shall be used.

a) Aperture diameters

The aperture diameters used for measurements of radiation for classification purposes shall be as shown in table 10.

NOTE Irradiance and radiant exposure values should not be averaged over apertures smaller than the limiting apertures given in table 10 for irradiance and radiant exposure.

b) Measurement distance

For condition 1, the measurement distance specified in table 10 refers to the distance between the closest point of human access and the aperture stop; for condition 2 and irradiance or radiant exposure measurements the measurement distance refers to the distance between the apparent source and the aperture stop. Outside the wavelength range of 302,5 nm and 4 000 nm, the differentiation into condition 1 and condition 2 does not apply and the distance specified in table 10 refers to the distance between the closest point of human access and the aperture stop.

For the purpose of this standard, the location of the beam waist shall be considered as the location of the apparent source in determining the measurement distance as given in table 10; however, the location and size of the beam waist should not be used to geometrically determine the angular subtense of the apparent source. If a value of angular subtense greater than α_{min} is to be used for classification, the dimensions of the apparent source shall be determined. In the case of scanning beams, the appropriate measurement location is the location where the combination of angular subtense and pulse duration results in the most restrictive accessible emission limit (AEL).

NOTE For the measurement of power and energy for condition 2 and the measurement of irradiance or radiant exposure in the wavelength range of 302,5 nm to 4 000 nm. In cases where the apparent source is not accessible by virtue of engineering design (for example, recessed), the measurement distance should be at the closest point of human access but not less than the specified distance.

If the source is not recessed, instead of a 7 mm diameter aperture stop placed at a distance r as determined by the formula in a) of table 10 for thermal limits, an aperture stop with varying diameter d can be placed at a distance of 100 mm from the apparent source. In this case, the diameter of the aperture is determined by the formula:

$$d = (7\,\text{mm})\sqrt{\frac{\alpha_{max}}{\alpha + 0{,}46\,\text{mrad}}} \quad \text{If } \alpha < \alpha_{min},\ d = 50\text{ mm. If } \alpha \geq \alpha_{max},\ d = 7\text{ mm}$$

NOTE The measurement apertures and distances in table 10 describe the geometry of the measurement conditions required to determine the radiation level to be used for classification. In some cases, it may be appropriate, because of instrument or space limitations, to use an equivalent arrangement of apertures and distances. For example, as an alternative to a 7 mm diameter aperture stop placed at a distance of 14 mm from the apparent source, an aperture stop with a diameter of 50 mm can be placed at a distance of 100 mm from the apparent source.

Table 10 – Diameters of the measurement apertures and measurement distances

Wavelength nm	**For values expressed in power W or energy J**				**For irradiance W/m² [b] or radiant exposure J/m² [b]**	
	Condition 1		**Condition 2**			
For Class 1 see also 9.2g) For Class 2 see also 9.2h)	**Aperture stop** mm	**Distance** mm	**Aperture stop** mm	**Distance** mm	**Limiting aperture** mm	**Distance** mm
< 302,5 nm	–	–	7	14	1	0
≥ 302,5 nm to 400 nm	25	2 000	7	14	1	100
≥ 400 nm to 1 400 nm	50	2 000	7 [a]	*r* [a]	7	100
≥ 1400 nm to 4 000 nm	25	2 000	7	14	1 for $t \le 0,35$ s $1,5\ t^{3/8}$ for $0,35\ \text{s} < t < 10$ s 3,5 for $t \ge 10$ s (t in s)	100
≥ 4 000 nm to 10^5 nm	–	–	7	14	1 for $t \le 0,35$ s $1,5\ t^{3/8}$ for $0,35\ \text{s} < t < 10$ s 3,5 for $t \ge 10$ s (t in s)	0
≥ 10^5 nm to 10^6 nm	–	–	7	14	11	0

[a] For the photochemical limits and $t \le 100$ s, r is given by

r = 14 mm for $\alpha \le 1,5$ mrad

r = 100 mm (α/11 mrad) for 1,5 mrad < $\alpha \le 11$ mrad

r = 100 mm for $\alpha > 11$ mrad

(for the test for Class 1M and 2M, refer to 9.2g) and h))

For the photochemical limits and $t > 100$ s, r is given by (for the definition of γ_p refer to 9.3c).

r = 14 mm for $\alpha \le 1,5$ mrad

$$r = \left(14 + 86\,\frac{\alpha - 1,5\ \text{mrad}}{\gamma_p - 1,5\ \text{mrad}}\right)\text{mm} \quad \text{for } 1,5\ \text{mrad} < \alpha \le \gamma_p$$

r = 100 mm for $\alpha > \gamma_p$

(for the test for Class 1M and 2M, refer to 9.2g) and h))

For the thermal limits, r is given by

$$r = (100\ \text{mm})\sqrt{\frac{\alpha + 0,46\ \text{mrad}}{\alpha_{max}}}$$ if $\alpha < \alpha_{min}$, r = 14 mm. If $\alpha \ge \alpha_{max}$, r = 100 mm

(for the test for Class 1M and 2M, refer to 9.2g) and h)).

[b] In the wavelength range of 400 nm to 4 000 nm, these values are also applicable for the measurement of power or energy for Class 1M and Class 2M (see 9.2g) and h)).

c) Angle of acceptance

i) Photochemical retinal limits

For measurements of sources to be evaluated against the photochemical limits (400 nm to 600 nm), the limiting angle of acceptance γ_p is

for 10 s < $t \le 100$ s: γ_p = 11 mrad

for 100 s < $t \le 10^4$ s: $\gamma_p = 1,1\ t^{0,5}$ mrad

for 10^4 s < $t \le 3 \cdot 10^4$ s: γ_p = 110 mrad

If the angular subtense of the source α is larger than the specified limiting angle of acceptance γ_p, the angle of acceptance should not be larger than the values specified for γ_p. If the angular subtense of the source α is smaller than the specified limiting angle of acceptance γ_p, the angle of acceptance shall fully encompass the source under consideration but need otherwise not be well defined (i.e. the angle of acceptance need not be restricted to γ_p).

NOTE For measurements of single small sources, where $\alpha < \gamma_p$ it will not be necessary to measure with a specific, well-defined angle of acceptance. To obtain a well-defined angle of acceptance, the angle of acceptance can be defined by either imaging the source onto a field stop or by masking off the source – see figures 16a and 16b respectively.

ii) All other limits

For measurement of radiation to be compared to limits other than the photochemical limits, the angle of acceptance shall fully encompass the source under consideration (i.e. the angle of acceptance shall be at least as large as the angular subtense of the source α). However, if $\alpha > \alpha_{max}$, in the wavelength range of 302,5 nm to 4 000 nm, the limiting angle of acceptance is α_{max} (100 mrad). Within the wavelength range of 400 nm to 1 400 nm, for the evaluation of an apparent source which consists of multiple points, the angle of acceptance has to be varied in the range of $\alpha_{min} \leq \gamma \leq \alpha_{max}$ (see 8.4d)).

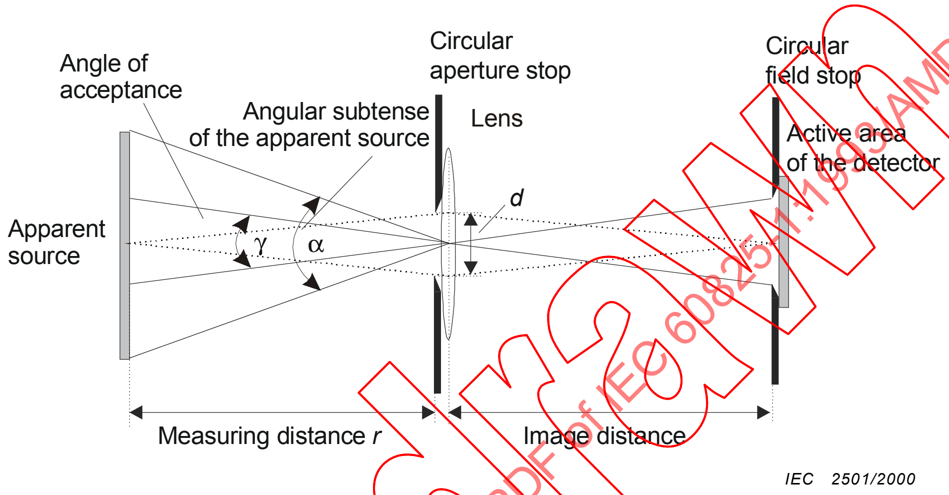

Figure 16a

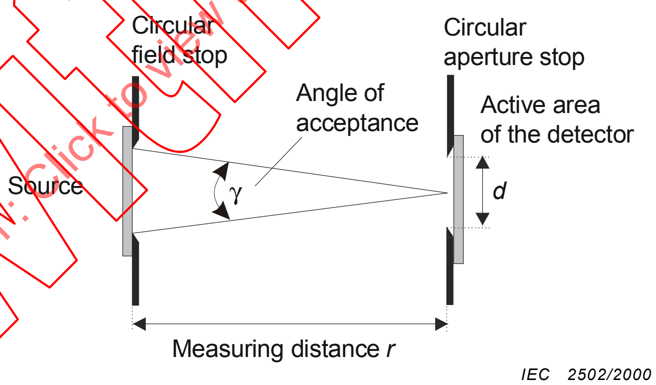

Figure 16b

Figure 16 – Measurement set-up to obtain a well-defined angle of acceptance – 16a: by imaging the apparent source onto the plane of the field stop – 16b: by placing a circular aperture or a mask (serving as field stop) close to the source

The angle of acceptance is determined by the ratio of the diameter of the field stop and the lens-field stop distance (image distance) (figure 16a), or by the ratio of the diameter of the field stop and the source-detector distance (figure 16b). Transmission and reflection losses due to the lens have to be taken into account. The measuring distance r as specified in table 10 is taken from the aperture stop.

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Replace the existing table 1 by the following new table 1:

Table 1 – Accessible emission limits for Class 1 and Class 1M laser products [a,b,c]

Wave-length λ in nm \ Exposure time t in s	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to $1,8 \times 10^{-5}$	$1,8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 0,35	0,35 to 10	10 to 10^2	10^2 to 10^3	10^3 to 10^4	10^4 to 3×10^4
180 to 302,5	3×10^{10} W·m^{-2}		30 J·m^{-2}									
302,5 to 315	$2,4 \times 10^4$ W		($t \le T_1$) $7,9 \times 10^{-7}\ C_1$ J / ($t > T_1$) $7,9 \times 10^{-7}\ C_2$ J						$7,9 \times 10^{-7}\ C_2$ J			
315 to 400			$7,9 \times 10^{-7}\ C_1$ J						$7,9 \times 10^{-3}$ J		$7,9 \times 10^{-6}$ W	
400 to 700[d]	$5,8 \times 10^{-9}\ C_6$ J	$1,0\ t^{0,75}\ C_6$ J	$2 \times 10^{-7}\ C_6$ J	$7 \times 10^{-4}\ t^{0,75}\ C_6$ J				400 to 600 nm[d]: Retinal photochemical hazard	$3,9 \times 10^{-3}\ C_3$ J using γ_p = 11 mrad	$3,9 \times 10^{-5}\ C_3$ W using $\gamma_p = 1,1\ t^{0,5}$ mrad		$3,9 \times 10^{-5}\ C_3$ W using γ_p = 110 mrad
								AND[d]				
								400 to 700 nm[d]: Retinal thermal hazard	($t \le T_2$) $7 \times 10^{-4}\ t^{0,75}\ C_6$ J / ($t > T_2$) α ≤ 1,5 mrad: $3,9 \times 10^{-4}$ W; α >1,5 mrad: $7 \times 10^{-4}\ C_6\ T_2^{-0,25}$ W			
700 to 1 050	$5,8 \times 10^{-9}\ C_4\ C_6$ J	$1,0\ t^{0,75}\ C_4\ C_6$ J	$2 \times 10^{-7}\ C_4\ C_6$ J	$7 \times 10^{-4}\ t^{0,75}\ C_4\ C_6$ J					($t \le T_2$) $7 \times 10^{-4}\ t^{0,75}\ C_4\ C_6\ C_7$ J / ($t > T_2$) α ≤ 1,5 mrad: $3,9 \times 10^{-4}\ C_4\ C_7$ W; α > 1,5 mrad: $7 \times 10^{-4}\ C_4\ C_6\ C_7 T_2^{-0,25}$ W			
1 050 to 1 400	$5,8 \times 10^{-8}\ C_6\ C_7$ J	$10,4\ t^{0,75}\ C_6\ C_7$ J	$2 \times 10^{-6}\ C_6\ C_7$ J			$3,5 \times 10^{-3}\ t^{0,75}\ C_6\ C_7$ J						
1 400 to 1 500	8×10^5 W		8×10^{-4} J				$4,4 \times 10^{-3}\ t^{0,25}$ J	$10^{-2}\ t$ J	$1,0 \times 10^{-2}$ W			
1 500 to 1 800	8×10^6 W		8×10^{-3} J					$1,8 \times 10^{-2}\ t^{0,75}$ J				
1 800 to 2 600	8×10^5 W		8×10^{-4} J				$4,4 \times 10^{-3}\ t^{0,25}$ J	$10^{-2}\ t$ J				
2 600 to 4 000	8×10^4 W		8×10^{-5} J	$4,4 \times 10^{-3}\ t^{0,25}$ J								
4 000 to 10^6	10^{11} W·m^{-2}		100 J·m^{-2}	5 600 $t^{0,25}$ J·m^{-2}					1 000 W·m^{-2}			

[a] For correction factors and units, see "Notes to tables 1 to 4".

[b] The AELs for emission durations less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

[c] The angle γ_p is the limiting angle of acceptance for the measuring instrument.

[d] In the wavelength range between 400 nm and 600 nm, dual limits apply and a product's emission must not exceed either limit applicable to the class assigned. If exposure times between 1 s and 10 s are used, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of $3,9 \times 10^{-3}\ C_3$ J is extended to 1 s.

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Replace the title of table 2 by the following:

Table 2 – Accessible emission limits for Class 2 and Class 2M laser products

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Replace the existing table 3 by the following new table 3:

Table 3 – Accessible emission limits for Class 3R laser products [a, b]

<table>
<tr><th>Exposure time t in s / Wavelength λ in nm</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to 10^{-7}</th><th>10^{-7} to $1,8 \times 10^{-5}$</th><th>$1,8 \times 10^{-5}$ to 5×10^{-5}</th><th>5×10^{-5} to 1×10^{-3}</th><th>1×10^{-3} to 0,35</th><th>0,35 to 10</th><th>10 to 10^3</th><th>10^3 to 3×10^4</th></tr>
<tr><td>180 to 302,5</td><td colspan="2">Not appropriate</td><td colspan="8">Not appropriate</td></tr>
<tr><td>302,5 to 315</td><td colspan="2" rowspan="2">$1,2 \times 10^5$ W</td><td colspan="6">$(t \le T_1)$ 4×10^{-6} C_1 J
$4,0 \times 10^{-6}$ C_2 J $(t > T_1)$</td><td colspan="2">$4,0 \times 10^{-6}$ C_2 J</td></tr>
<tr><td>315 to 400</td><td colspan="6">$4,0 \times 10^{-6}$ C_1 J</td><td>$4,0 \times 10^{-2}$ J</td><td>$4,0 \times 10^{-5}$ W</td></tr>
<tr><td>400 to 700</td><td>$2,9 \times 10^{-8}$ C_6 J</td><td>$5,0$ $t^{0,75}$ C_6 J</td><td colspan="2">1×10^{-6} C_6 J</td><td colspan="3">$(t < 0,25$ s$)$ $3,5 \times 10^{-3}$ $t^{0,75}$ C_6 J
$5,0 \times 10^{-3}$ C_6 W $(t \ge 0,25$ s$)$</td><td>$5,0 \times 10^{-3}$ C_6 W</td><td colspan="2">$5,0 \times 10^{-3}$ C_6 W</td></tr>
<tr><td>700 to 1 050</td><td>$2,9 \times 10^{-8}$ C_4 C_6 J</td><td>$5,0$ $t^{0,75}$ C_4 C_6 J</td><td colspan="2">1×10^{-6} C_4 C_6 J</td><td colspan="4">$3,5 \times 10^{-3}$ $t^{0,75}$ C_4 C_6 J</td><td colspan="2" rowspan="2">$\alpha \le 1,5$ mrad: $2,0 \times 10^{-3}$ C_4 C_7 W
$\alpha > 1,5$ mrad: $3,5 \times 10^{-3}$ C_4 C_6 C_7 $T_2^{-0,25}$ W $(t > T_2)$
$(t \le T_2)$ $3,5 \times 10^{-3}$ $t^{0,75}$ C_4 C_6 C_7 J</td></tr>
<tr><td>1 050 to 1 400</td><td>$2,9 \times 10^{-7}$ C_6 C_7 J</td><td>52 $t^{0,75}$ C_6 C_7 J</td><td colspan="3">1×10^{-5} C_6 C_7 J</td><td colspan="3">$1,8 \times 10^{-2}$ $t^{0,75}$ C_6 C_7 J</td></tr>
<tr><td>1 400 to 1 500</td><td colspan="2">4×10^6 W</td><td colspan="4">4×10^{-3} J</td><td>$2,2 \times 10^{-2}$ $t^{0,25}$ J</td><td>5×10^{-2} t J</td><td colspan="2" rowspan="4">$5,0 \times 10^{-2}$ W</td></tr>
<tr><td>1 500 to 1 800</td><td colspan="2">4×10^7 W</td><td colspan="5">4×10^{-2} J</td><td>9×10^{-2} $t^{0,75}$ J</td></tr>
<tr><td>1 800 to 2 600</td><td colspan="2">4×10^6 W</td><td colspan="4">4×10^{-3} J</td><td>$2,2 \times 10^{-2}$ $t^{0,25}$ J</td><td rowspan="2">5×10^{-2} t J</td></tr>
<tr><td>2 600 to 4 000</td><td colspan="2">4×10^5 W</td><td>4×10^{-4} J</td><td colspan="4">$2,2 \times 10^{-2}$ $t^{0,25}$ J</td></tr>
<tr><td>4 000 to 10^6</td><td colspan="2">5×10^{11} W·m^{-2}</td><td>500 J·m^{-2}</td><td colspan="5">$2,8 \times 10^4$ $t^{0,25}$ J·m^{-2}</td><td colspan="2">5 000 W·m^{-2}</td></tr>
</table>

[a] For correction factors and units, see "Notes to tables 1 to 4".

[b] The AELs for emission durations less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

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Notes to tables 1 to 4

Replace these notes by the following:

NOTE 1 There is only limited evidence about effects for exposures of less than 10^{-9} s for wavelengths less than 400 nm and greater than 1 400 nm. The AELs for these exposure times and wavelengths have been derived by calculating the equivalent radiant power or irradiance from the radiant power or radiant exposure applying at 10^{-9} s for wavelengths less than 400 nm and greater than 1 400 nm.

NOTE 2 Correction factors C_1 to C_7 and breakpoints T_1 and T_2 used in tables 1 to 4 are defined in the following expressions and are illustrated in figures 1 to 8.

Parameter	Spectral region nm	Figures
$C_1 = 5{,}6 \times 10^3\ t^{0{,}25}$	302,5 to 400	1
$T_1 = 10^{0{,}8(\lambda - 295)} \times 10^{-15}$ s	302,5 to 315	2
$C_2 = 10^{0{,}2(\lambda - 295)}$	302,5 to 315	3
$T_2 = 10 \times 10^{[(\alpha - \alpha_{min})/98{,}5]}$ s[a]	400 to 1 400	4
$C_3 = 1{,}0$	400 to 450	5
$C_3 = 10^{0{,}02(\lambda - 450)}$	450 to 600	5
$C_4 = 10^{0{,}002(\lambda - 700)}$	700 to 1 050	6
$C_4 = 5$	1 050 to 1 400	6
$C_5 = N^{-1/4}$ [b]	400 to 10^6	7
$C_6 = 1$ for $\alpha \le \alpha_{min}$	400 to 1 400	[c]
$C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \le \alpha_{max}$	400 to 1 400	[c]
$C_6 = \alpha_{max}/\alpha_{min} = 66{,}7$ for $\alpha > \alpha_{max}$[d]	400 to 1 400	[c]
$C_7 = 1$	700 to 1 150	8
$C_7 = 10^{0{,}018(\lambda - 1150)}$	1 150 to 1 200	8
$C_7 = 8$	1 200 to 1 400	8

[a] T_2 = 10 s for α < 1,5 mrad and T_2 = 100 s for α > 100 mrad

[b] C_5 is only applicable to pulse durations shorter than 0,25 s.

[c] C_6 is only applicable to pulsed lasers and to CW lasers where thermal injury dominates (see table 1)

[d] The limiting angle of acceptance γ_p shall be equal to α_{max}

α_{min} = 1,5 mrad

α_{max} = 100 mrad

N is the number of pulses contained within the applicable duration (see 8.4f) and 13.3)

NOTE 3 See table 7 for limiting apertures.

NOTE 4 In the formulae in the tables 1 to 4 and in these notes, the wavelength has to be expressed in nanometres, the emission duration *t* has to be expressed in seconds and α has to be expressed in milliradians.

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10.1 General

Replace in the first paragraph, the fourth, fifth and sixth sentences as follows:

Nothing in this section shall be considered as constraints or requirements imposed upon the manufacturer.

For installations where Class 3R laser products emitting energy outside of the 400 nm to 700 nm wavelength range or Class 3B or Class 4 laser products are operated, a laser safety officer should be appointed. It should be the laser safety officer's responsibility to review the following precautions and designate the appropriate controls to be implemented.

10.2 Use of remote interlock connector

Replace the first paragraph, as follows:

The remote interlock connector of Class 3B and Class 4 lasers should be connected to an emergency master disconnect interlock or to room, door or fixture interlocks (see 4.4).

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10.3 Key control

Replace the existing text as follows:

Class 3B and Class 4 laser products not in use should be protected against unauthorized use by removal of the key from the key control (see 4.5).

10.4 Beam stop or attenuator

Replace the existing text as follows:

The inadvertent exposure of bystanders to laser radiation from Class 3B or Class 4 laser products should be prevented by the use of a beam attenuator or beam stop (see 4.7).

10.6 Beam paths

Replace the existing text as follows:

The beam emitted by each Class 1M and Class 2M laser product classified under condition 1 of table 10, each Class 3R laser product emitting energy outside of the 400 nm to 700 nm wavelength range, and each Class 3B or Class 4 laser product should be terminated at the end of its useful path by a diffusely reflecting material of appropriate reflectivity and thermal properties or by absorbers.

Open laser beam paths should be located above or below eye level where practicable.

The beam paths of Class 3R laser products emitting energy outside of the 400 nm to 700 nm wavelength range and Class 3B or Class 4 laser products should be as short as practicable, should have a minimum number of directional changes, should avoid crossing walkways and other access routes, and should, where practicable, be enclosed. The beam enclosure (for example, a tube) should be securely mounted but preferably not rigidly attached to (or provide support for) beam-forming components.

10.7 Specular reflections

Replace the existing text as follows:

Care should be exercised to prevent the unintentional specular reflection of radiation from Class 3R, Class 3B or Class 4 laser products. Mirrors, lenses and beam splitters should be rigidly mounted and should be subject to only controlled movements while the laser is emitting.

Care should be exercised to prevent the unintentional specular reflection of radiation from Class 1M and Class 2M laser products from surfaces that may focus the beam.

Reflecting surfaces that appear to be diffuse may actually reflect a considerable part of the radiation beam specularly, especially in the infra-red spectral range. This may be potentially hazardous for longer distances than one would expect for purely (Lambertian) diffuse reflections.

Special care needs to be taken in the selection of optical components for Class 3B and Class 4 lasers and in maintaining the cleanliness of their surfaces.

Potentially hazardous specular reflections occur at all surfaces of transmissive optical components such as lenses, prisms, windows and beam splitters.

Potentially hazardous radiation can also be transmitted through some reflective optical components such as mirrors (for example, infra-red radiation passing through a reflector of visible radiation).

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10.8 Eye protection

Replace the existing text of the second paragraph as follows and make it the first paragraph:

Eye protection which is designed to provide adequate protection against specific laser wavelengths should be used in all hazard areas where Class 3R laser products emitting energy outside of the 400 nm to 700 nm wavelength range, Class 3B or Class 4 lasers are in use (see clause 12). Exceptions to this are

a) when engineering and administrative controls are such as to eliminate potential exposure in excess of the applicable MPE;
b) when, due to the unusual operating requirements, the use of eye protection is not practicable. Such operating procedures should only be undertaken with the approval of the laser safety officer.

Page 75

10.8.3 Protective eyewear

Replace the second paragraph as follows:

Special attention has to be given to the resistance and stability against laser radiation when choosing eyewear for protection against Class 4 lasers.

10.9 Protective clothing

Replace the second paragraph as follows:

Special attention has to be given to the resistance and stability against laser radiation when choosing clothing for protection against Class 4 lasers.

10.10 Training

Replace the first paragraph as follows:

Operation of Class 1M and Class 2M laser products that failed condition 1 of table 10, Class 3R, Class 3B and Class 4 laser systems can represent a hazard not only to the user but also to other people over a considerable distance.

Page 77

11.3 Electrical hazards

Replace the first paragraph as follows:

Many lasers make use of high voltages (>1 kV), and pulsed lasers are especially dangerous because of the stored energy in the capacitor banks.

Page 79

11.5 Materials processing

Replace the text as follows:

Specifications for laser products used to process materials may vary according to their intended use. If the users wish to process materials other than those recommended by the manufacturers, they should make themselves aware of the different degrees of risk and hazards associated with the processing of such materials, and take appropriate precautions to prevent, for example, the emission of toxic fume, fire, explosion or reflection of laser radiation from the workpiece.

Page 81

12.2 Hazard evaluation for Class 3B and Class 4 lasers used outdoors

Replace the title and text as follows:

12.2 Hazard evaluation for lasers used outdoors

The hazard potential for Class 1M and Class 2M laser products that failed condition 1 of table 10, Class 3R lasers emitting energy outside of the 400 nm to 700 nm wavelength range, Class 3B and Class 4 lasers may extend over a considerable distance. The range from the laser at which the irradiance or radiant exposure falls below the appropriate MPE is termed the nominal ocular hazard distance (NOHD). The area within which the beam irradiance or radiant exposure exceeds the appropriate MPE is called the nominal ocular hazard area (NOHA). This area is bounded by the limits of traverse, elevation and pointing accuracy of the laser system and extends either to the limit of the NOHD or to the position of any target or backstop. The exact NOHA will also depend on the nature of any material within the beam path, for example, specular reflectors.

If laser products are classified as Class 1M or Class 2M because they fail condition 1 of table 10, they may represent a hazard when large diameter viewing optics, such as magnifiers or telescopes, are used.

The NOHD is dependent on the output characteristics of the laser, the appropriate MPE, the type of optical system used, and the effect of the atmosphere on beam propagation. Formulae and examples for calculating the NOHD are given in annex A.

Page 81

12.3 Personal protection

Replace the first paragraph as follows:

The need to use personal protection against the hazardous effects of laser operation should be kept to a minimum using engineering design, beam enclosures and administrative controls.

12.4 Laser demonstrations, displays and exhibitions

Replace the text as follows:

Only Class 1 or Class 2 laser products should be used for demonstration, display or entertainment in unsupervised areas. The use of other classes of lasers for such purposes should be permitted only when the laser operation is under the control of an experienced, well-trained operator and/or when spectators are prevented from exposure to levels exceeding the applicable MPE.

Each demonstration laser product used for educational purposes in schools, etc. should comply with all of the applicable requirements for a Class 1 or Class 2 laser product. A demonstration laser product shall not permit human access to laser radiation in excess of the accessible emission limits of Class 1 or Class 2 as applicable.

NOTE Additional guidance can be found in IEC 60825-3, a technical report on the safety precautions for laser light shows and displays.

Page 83

12.5.1 Class 2 and Class 3A laser products

Replace the title and text as follows:

12.5.1 Class 1M, Class 2, Class 2M and Class 3R laser products

Precautions are only required to prevent continuous viewing of the direct beam; for Class 1M, Class 2 and Class 2M, a momentary (0,25 s) exposure to radiation in the wavelength range 400 nm to 700 nm as would occur in accidental viewing situations is not considered hazardous. However, the laser beam should not be intentionally aimed at people. The use of optical viewing aids (for example, binoculars) with Class 1M, Class 2M and Class 3R laser products may increase the ocular hazard. Additional precautions for Class 1M, Class 2M and Class 3R laser products are given in 12.6.2.

12.5.3 Class 4 laser products

Replace the first paragraph as follows:

Class 4 laser products can cause injury from either the direct beam or its specular reflections and from diffuse reflections. They also present a potential fire hazard. The following controls should be employed in addition to those of 12.5.2 to minimize these risks.

On page 85, in item d), last sentence, replace "…at such as angle…" *by* "…at such an angle…"

In item e), replace, "…opaque to…" *by* "…opaque at…" *and in the brackets replace the word* "become" *by* "be".

Page 85

12.6.2 Class 3A laser products used for surveying, alignment and levelling

Replace the title and items a), b) and d) as follows:

12.6.2 Class 1M, Class 2M and Class 3R laser products used for surveying, alignment and levelling

a) Only qualified and trained persons should be assigned to install, adjust and operate the laser equipment.

b) Areas in which these lasers are used should be posted with an appropriate laser warning sign.

d) Precautions should be taken to ensure that persons do not look directly into the beam (prolonged intrabeam viewing can be hazardous). Direct viewing of the beam through optical instruments (theodolite, etc.) may also be hazardous, particularly for Class 1M and Class 2M lasers that failed condition 1 of table 10, and should not be permitted unless specifically approved by a laser safety officer.

On page 87, modify item g) as follows:

g) Precautions should be taken to ensure that the laser beam is not unintentionally directed at mirror-like (specular) surfaces (but, more importantly, at flat or concave mirror-like surfaces).

Page 87

12.6.4 Lasers for surveying, alignment, and levelling

Replace the text as follows:

Lasers of Class 1 or Class 2 should be used for surveying, alignment, and levelling applications whenever practicable. There may be situations, however, where high ambient light levels require the use of lasers of higher output power. If Class 1M, Class 2M and Class 3R lasers are used, the requirements of 12.6.2 should be followed. In those exceptional cases where Class 3B lasers are necessary, the requirements of 12.6.3 should be followed. In addition, human access should not be permitted to laser radiation in the wavelength range from 400 nm to 700 nm with a radiant power that exceeds 5×10^{-3} W for any emission duration exceeding $3{,}8 \times 10^{-4}$ s nor should human access be permitted to laser radiation in excess of the AEL for Class 1 for any other combination of emission duration and wavelength range.

Page 89

13.1 General remarks

Replace a) in the second paragraph by the following:

a) the pulse width or exposure duration are within one order of magnitude, and

Table 5 – Additivity of effects on eye (o) and skin (s) of radiation of different spectral regions

*Add an asterisk ** with o of the* "Visible and IR-A" *and* "Visible and IR-A" box.

Add below table 5:

** Where AELs and ocular MPEs are being evaluated for time bases or exposure durations of 1 s or longer, then the additive photochemical effects (400 nm to 600 nm) and the additive thermal effects (400 nm to 1 400 nm) shall be assessed independently and the most restrictive value used.

13.2 Limiting apertures

Replace, on page 91, the existing note by the following:

NOTE The values of ocular exposures in the wavelength range 400 nm to 1 400 nm are measured over a 7 mm diameter aperture (pupil). The MPE value is not to be adjusted to take into account smaller pupil diameters.

Page 91

13.3 Repetitively pulsed or modulated lasers

Replace the second sentence of the first paragraph by the following:

The following methods should be used to determine the MPE to be applied to repetitive exposures to repetitively pulsed radiation.

Replace the second and third paragraphs by the following:

The MPE for ocular exposure for wavelengths from 400 nm to 10^6 nm is determined by using the most restrictive of requirements a), b) and c). Requirement c) applies only to the thermal limits and not to the photochemical limits.

The MPE for ocular exposure for wavelengths less than 400 nm and the MPE for skin exposure is determined by using the most restrictive of requirements a) and b).

Replace "duration T" *in item b) by* "exposure duration T" *(twice).*

Modify the beginning of item c) to read:

c) The average exposure from pulses within a pulse train shall not ...

Insert the following note before the formula for MPE_{train}:

NOTE 1 The exposures in a pulse train are to be averaged over the same emission duration which was used to determine N. Every averaged pulse exposure is to be compared to the reduced MPE_{train} as specified below:

Add at the end of item c):

If pulses of variable amplitude are used, the assessment is made for pulses of each amplitude separately, and for the whole train of pulses.

The maximum exposure duration for which requirement c) should be applied is T_2 in the wavelength range from 400 nm to 1 400 nm (as defined in notes to tables 1 to 4) and 10 s for longer wavelengths.

NOTE 2 C_5 is only applicable to individual pulse durations shorter than 0,25 s.

NOTE 3 If multiple pulses appear within the period of T_i (see table 9) they are counted as a single pulse to determine N and the radiant exposure of the individual pulses are added to be compared to the MPE of T_i, provided that all individual pulse durations are greater than 10^{-9} s.

NOTE 4 The exposure from any group of pulses (or sub-group of pulses in a train) delivered in any given time should not exceed the MPE for that time.

NOTE 5 In cases of varying pulse widths or pulse intervals, the total-on-time-pulse (TOTP) method may be used in place of requirement c). In this case, the MPE is determined by the duration of the TOTP, which is the sum of all pulse durations within the exposure duration or T_2, whichever is smaller. Pulses with durations less than T_i, are assigned pulse durations of T_i. If two or more pulses occur within a duration of T_i, these pulse groups are assigned pulse durations of T_i. For comparison with the MPE for the corresponding duration, all individual pulse radiant exposures are added.

This method is equivalent to requirement c) when the average radiant exposure of pulses is compared to the MPE of a single pulse multiplied with C_5.

Subclause 13.4.1

Add the title and replace the first sentence as follows:

13.4.1 Limiting aperture

The values of exposure or irradiance to be compared to the respective MPE shall be averaged over a circular aperture stop according to the limiting apertures of table 7.

Replace the second sentence with the following:

"For ocular exposure in the wavelength range from 400 nm to 1 400 nm a minimum measurement distance of 100 mm shall be used."

Page 93

Replace subclause 13.4.2 as follows:

13.4.2 Angle of acceptance

i) Photochemical retinal limits

For measurements of sources to be evaluated against the photochemical limits (400 nm to 600 nm), the limiting angle of acceptance γ_p is

for 10 s < $t \leq$ 100 s: γ_p = 11 mrad

for 100 s < $t \leq 10^4$ s: γ_p = 1,1 $t^{0,5}$ mrad

for 10^4 s < $t \leq 3 \times 10^4$ s: γ_p = 110 mrad

If the angular subtense of the source α is larger than the specified limiting angle of acceptance γ_p, the angle of acceptance should not be larger than the values specified for γ_p. If the angular subtense of the source α is smaller than the specified limiting angle of acceptance γ_p, the angle of acceptance shall fully encompass the source under consideration but need otherwise not be well defined (i.e. the angle of acceptance need not be restricted to γ_p).

NOTE For measurements of single small sources, where $\alpha < \gamma_p$, it will not be necessary to measure with a specific, well-defined, angle of acceptance. To obtain a well-defined angle of acceptance, the angle of acceptance can be defined by either imaging the source onto a field stop or by masking off the source – see figures 16a and 16b of 9.3 respectively.

ii) All other limits

For measurement of radiation to be compared to limits other than the retinal photochemical hazard limit, the angle of acceptance shall fully encompass the source under consideration (i.e. the angle of acceptance shall be at least as large as the angular subtense of the source α). However, if $\alpha > \alpha_{max}$, in the wavelength range of 302,5 nm to 4 000 nm, the limiting angle of acceptance shall not be larger than α_{max} (0,1 rad) for the thermal hazard limits. Within the wavelength range of 400 nm to 1 400 nm for thermal hazard limits, for the evaluation of an apparent source which consists of multiple points, the angle of acceptance shall be in the range of $\alpha_{min} \leq \gamma \leq \alpha_{max}$ (see 8.4 d)).

For the determination of the MPE for non-circular sources, the value of the angular subtense of a rectangular or linear source is determined by the arithmetic mean of the two angular dimensions of the source. Any angular dimension that is greater than α_{max} or less than α_{min} shall be limited to α_{max} or α_{min} respectively, prior to calculating the mean. The retinal photochemical hazard limits do not depend on the angular subtense of the source and the source is measured with the angle of acceptance as specified above.

13.5 Extended source lasers

Replace the first sentence of the first paragraph as follows:

The following corrections to the small source MPEs are restricted in most instances to viewing diffuse reflections, LEDs, and in some cases these could apply to laser arrays or extended source diffused laser products.

Replace the second paragraph and delete formulae for α_{min}:

For extended source laser radiation (for example, diffuse reflection viewing) at wavelengths from 400 nm to 1 400 nm, the thermal ocular hazard MPEs are increased by the factor C_6 provided that the angular subtense of the source (measured at the viewer's eye) is greater than α_{min}, where α_{min} is equal to 1,5 mrad.

Delete the note to 13.5.

Replace the existing table 6 with the following new table 6:

Table 6 – Maximum permissible exposure (MPE) at the cornea for direct exposure to laser radiation [a] [b] [c]

<table>
<tr><th>Exposure time t in s
Wave-length λ in nm</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to 10^{-7}</th><th>10^{-7} to $1,8 \times 10^{-5}$</th><th>$1,8 \times 10^{-5}$ to 5×10^{-5}</th><th>5×10^{-5} to 1×10^{-3}</th><th colspan="2">1×10^{-3} to 10</th><th>10 to 10^2</th><th>10^2 to 10^3</th><th>10^3 to 10^4</th><th>10^4 to 3×10^4</th></tr>
<tr><td>180 to 302,5</td><td colspan="2" rowspan="3">3×10^{10} W·m^{-2}</td><td colspan="10">30 J·m^{-2}</td></tr>
<tr><td>302,5 to 315</td><td colspan="6">($t \le T_1$) C_1 J·m^{-2}
C_2 J·m^{-2} ($t > T_1$)</td><td colspan="4">C_2 J·m^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="6">C_1 J·m^{-2}</td><td colspan="2">10^4 J m^{-2}</td><td colspan="2">10 W m^{-2}</td></tr>
<tr><td rowspan="5">400 to 700[d]</td><td rowspan="5">$1,5 \times 10^{-4}$ C_6 J·m^{-2}</td><td rowspan="5">$2,7 \times 10^4$ $t^{0,75}$ C_6 J·m^{-2}</td><td colspan="2" rowspan="5">5×10^{-3} C_6 J·m^{-2}</td><td colspan="3" rowspan="5">18 $t^{0,75}$ C_6 J·m^{-2}</td><td rowspan="3">400 to 600 nm[d]</td><td colspan="4">Retinal photochemical hazard</td></tr>
<tr><td>100 C_3 J·m^{-2} using γ_p = 11 mrad</td><td colspan="2">1 C_3 W·m^{-2} using γ_p = 1,1 $t^{0,5}$ mrad</td><td>1 C_3 W·m^{-2} using γ_p = 110 mrad</td></tr>
<tr><td colspan="4">AND[d]</td></tr>
<tr><td rowspan="2">400 to 700 nm[d]</td><td colspan="4">Retinal thermal hazard</td></tr>
<tr><td colspan="4">$\alpha \le 1,5$ mrad: 10 W·m^{-2}
$\alpha > 1,5$ mrad: 18 C_6 $T_2^{-0,25}$ W·m^{-2}
($t \le T_2$) 18 $t^{0,75}$ C_6 J·m^{-2} ($t > T_2$)</td></tr>
<tr><td>700 to 1 050</td><td>$1,5 \times 10^{-4}$ C_4 C_6 J·m^{-2}</td><td>$2,7 \times 10^4$ $t^{0,75}$ C_4 C_6 J·m^{-2}</td><td colspan="2">5×10^{-3} C_4 C_6 J·m^{-2}</td><td colspan="4">18 $t^{0,75}$ C_4 C_6 J·m^{-2}</td><td colspan="4" rowspan="2">$\alpha \le 1,5$ mrad: 10 C_4 C_7 W·m^{-2}
$\alpha > 1,5$ mrad: 18 C_4 C_6 C_7 $T_2^{-0,25}$ W·m^{-2}
($t \le T_2$) 18 $t^{0,75}$ C_4 C_6 C_7 J·m^{-2} ($t > T_2$)</td></tr>
<tr><td>1 050 to 1 400</td><td>$1,5 \times 10^{-3}$ C_6 C_7 J·m^{-2}</td><td>$2,7 \times 10^5$ $t^{0,75}$ C_6 C_7 J·m^{-2}</td><td colspan="3">5×10^{-2} C_6 C_7 J·m^{-2}</td><td colspan="3">90 $t^{0,75}$ C_6 C_7 J·m^{-2}</td></tr>
<tr><td>1 400 to 1 500</td><td colspan="2">10^{12} W·m^{-2}</td><td colspan="4">10^3 J·m^{-2}</td><td colspan="2">5 600 $t^{0,25}$ J·m^{-2}</td><td colspan="4" rowspan="4">1 000 W·m^{-2}</td></tr>
<tr><td>1 500 to 1 800</td><td colspan="2">10^{13} W·m^{-2}</td><td colspan="6">10^4 J·m^{-2}</td></tr>
<tr><td>1 800 to 2 600</td><td colspan="2">10^{12} W·m^{-2}</td><td colspan="4">10^3 J·m^{-2}</td><td colspan="2">5 600 $t^{0,25}$ J·m^{-2}</td></tr>
<tr><td>2 600 to 10^6</td><td colspan="2">10^{11} W·m^{-2}</td><td>100 J·m^{-2}</td><td colspan="5">5 600 $t^{0,25}$ J·m^{-2}</td></tr>
</table>

[a] For correction factors and units, see "Notes to tables 1 to 4".

[b] The MPEs for exposure times below 10^{-9} s and for wavelengths less than 400 nm and greater than 1 400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPEs for exposure times below 10^{-13} s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

[c] The angle γ_p is the limiting angle of acceptance for the measuring instrument.

[d] In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure must not exceed either limit applicable. Normally photochemical hazard limits only apply for exposure durations greater than 10 s; however, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of 100 C_3 J m^{-2} shall be applied for exposures greater than or equal to 1 s.

Page 97

Replace the existing table 7 with the following new table 7:

Table 7 – Aperture diameter applicable to measuring laser irradiance and radiant exposure

Spectral region nm	**Aperture diameter for**	
	Eye mm	**Skin** mm
180 to 400	1	3,5
≥ 400 to 1 400	7	3,5
≥ 1 400 to 10^5	1 for $t \leq 0,35$ s $1,5\ t^{3/8}$ for $0,35\ \text{s} < t < 10$ s 3,5 for $t \geq 10$ s.	3,5
≥ 10^5 to 10^6	11	11

Page 99

In table 8, change skin MPEs for λ = 1 400 nm to 10^6 nm to be identical to that of the cornea (given in table 6).

Page 101

Replace existing figures 4, 5, 10a, 10b, and 11 by the following new figures 4, 5, 10a, 10b, 11a and 11b.

$T_2 = 10$ $0 < \alpha < 1,5$

$T_2 = 10 \times 10^{[(\alpha - 1,5\ \text{mrad})/98,5]}$ $1,5 < \alpha < 100$

$T_2 = 100$ $\alpha > 100$

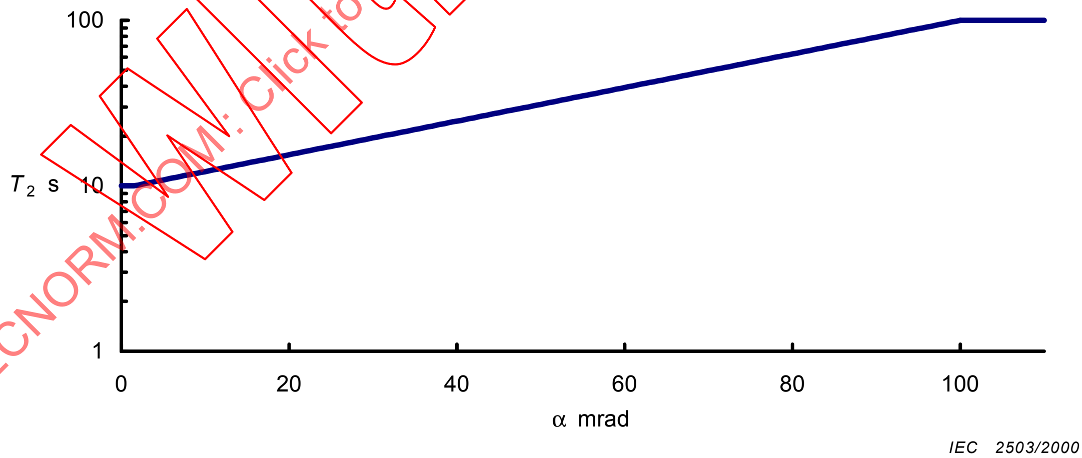

Figure 4 – Breakpoint T_2 for source size α ranging from 0 mrad to more than 100 mrad

$C_3 = 1$ for $(400 < \lambda < 450)$

$C_3 = 10^{0,02(\lambda-450)}$ for $(450 < \lambda < 600)$

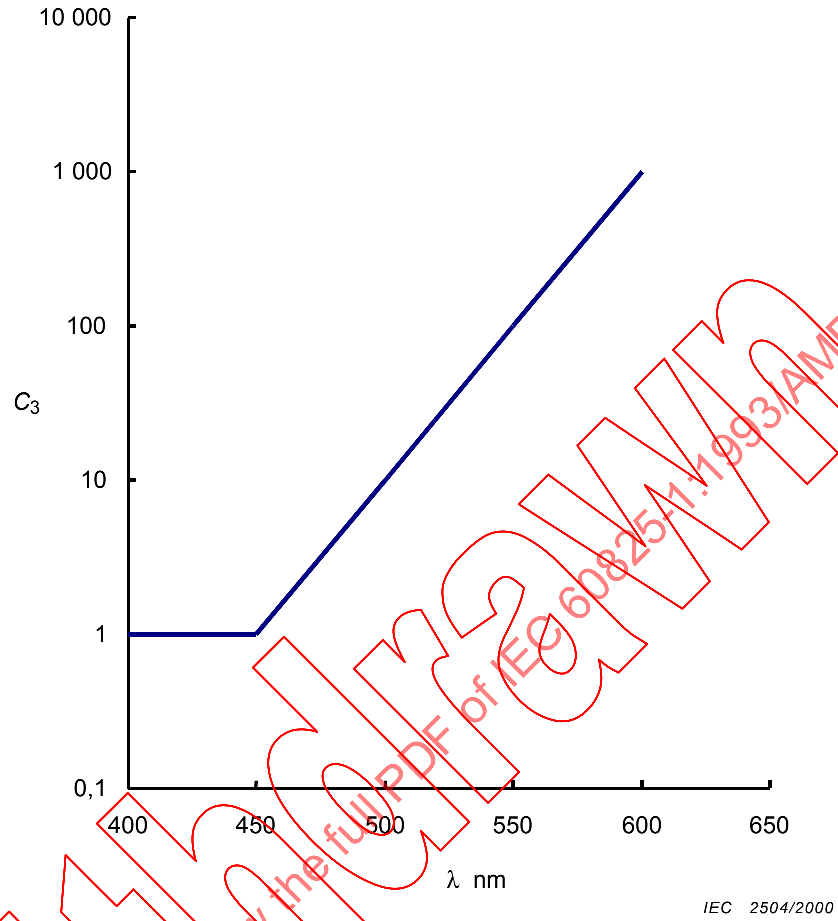

Figure 5 – Correction factor C_3 for λ = 400 nm to 600 nm

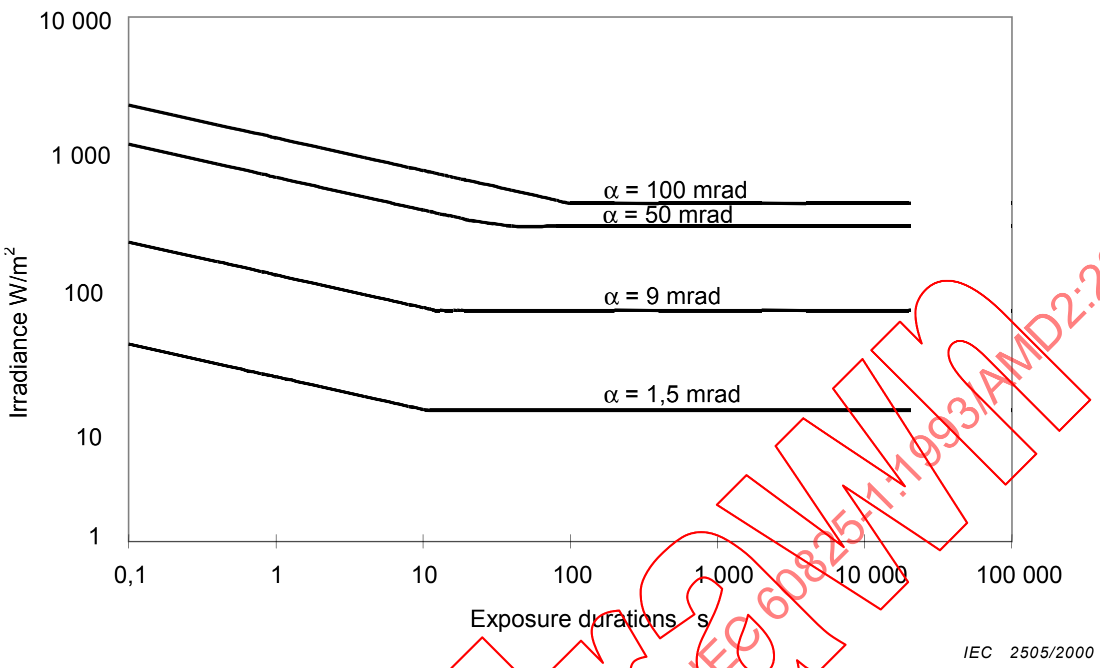

Figure 10a – MPE for direct ocular exposure to protect against thermal injury (λ = 400 nm to 700 nm) for exposure durations greater than 0,1 s for selected source sizes between 1,5 mrad and 100 mrad

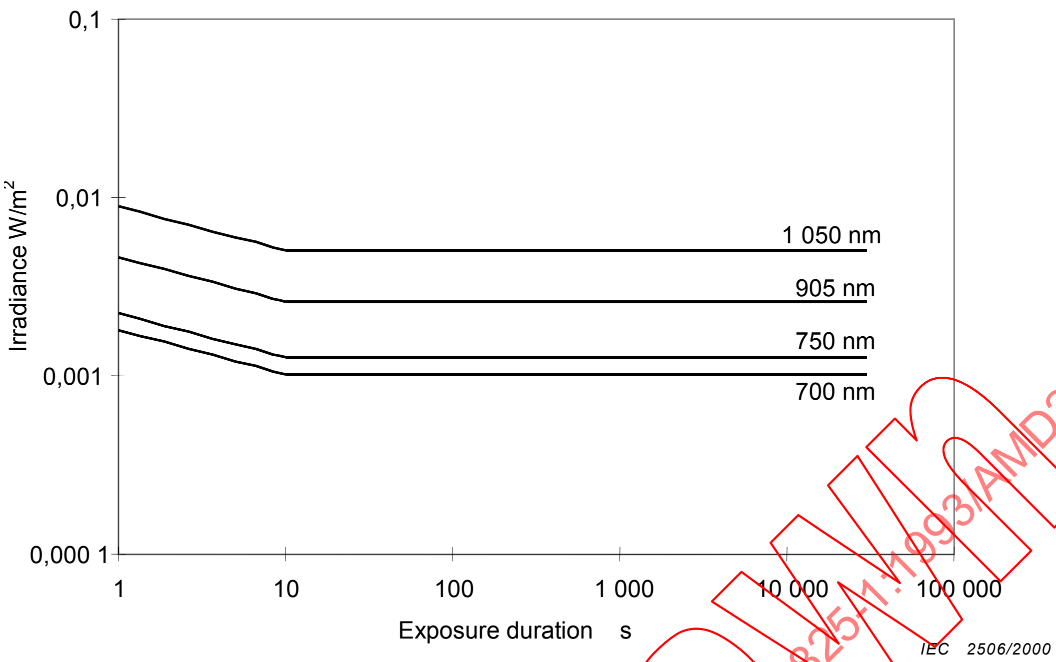

Figure 10b – MPE for direct ocular exposure (C_6 = 1) for exposure durations greater than 1 s for selected wavelengths between 700 nm and 1 050 nm

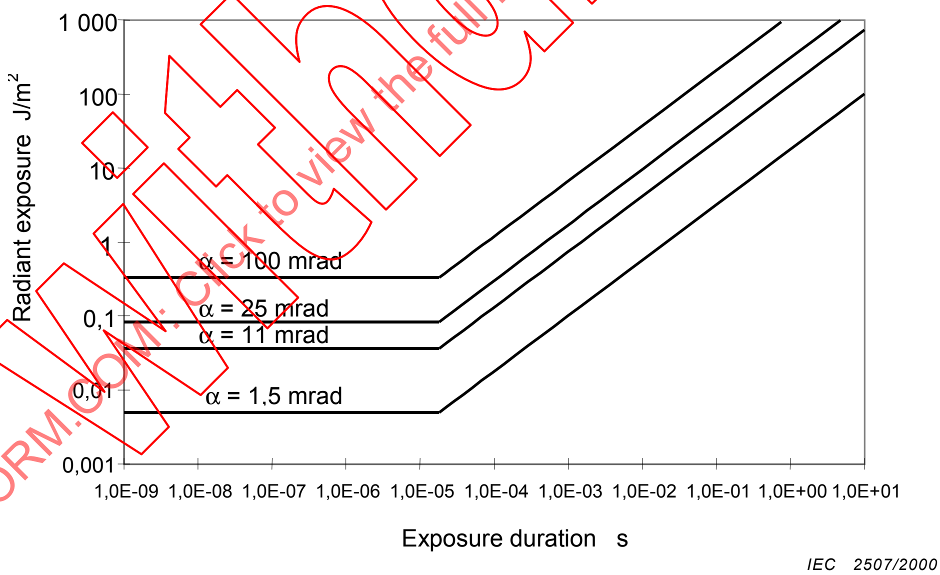

Figure 11a – MPE for ocular exposure (λ = 400 nm to 700 nm) to a single exposure at selected angular subtenses for the source

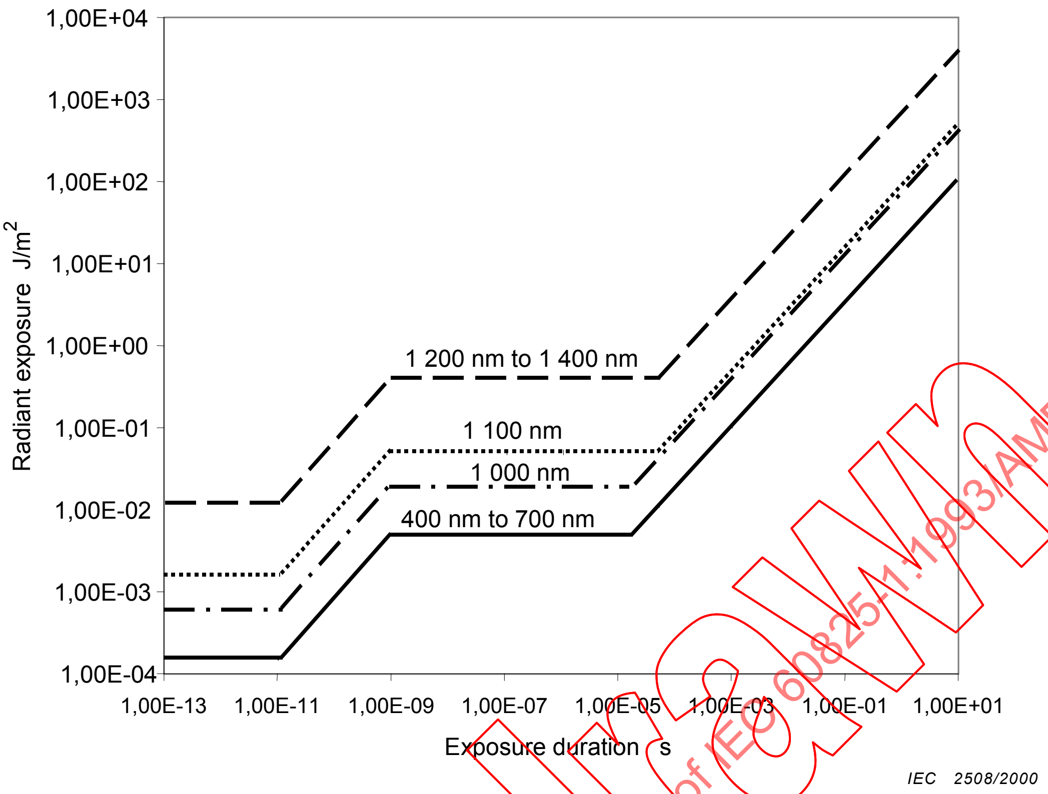

Figure 11b – MPE for ocular exposure at selected wavelengths from 400 nm to 1 400 nm and C_6 = 1

Page 115

Annex A

Examples of calculations

Replace definition for α by:

The angle subtended by an apparent source (or a diffuse reflection) as viewed at a point in space.

Page 117

Replace definition for N by:

Number of pulses contained within an exposure duration.

Page 121

A.2 Maximum permissible exposure (MPE) – Intrabeam viewing

Replace the title and first paragraph of this clause as follows:

A.2 Maximum permissible exposure (MPE) – Single and multiple small sources

Small-source viewing occurs when the angular subtense of the source is $\leq \alpha_{min}$. The following three examples illustrate the calculation procedures for single and multiple small-source viewing conditions.

Page 123

Example A.2-2, Solution

In the first line of the first paragraph replace "550 nm" *by* "400 nm".

Replace second paragraph "For intrabeam viewing, $\alpha < \alpha_{min}$, and C_6 = 1." *by* "For intrabeam viewing of a small source, $\alpha \leq \alpha_{min}$, and C_6 = 1 (see notes to tables 1 to 4)."

Example A.2-3, Solution

In the second last line, replace "point source" by "small source".

Page 125

Example A.2-4, Solution

> *This example was revised in amendment 1 and the following changes are referenced to the pages in amendment 1 (1997).*
>
> Amendment 1, page 9, second paragraph:
>
> *Delete the third sentence which begins* "in addition to grouping,...".

Amendment 1, page 9:

Add the following paragraph after the last equation on this page:

Since C_6 depends only on the angular subtense of the diode group, it has the same value in the equations for $E_{\text{MPE,train,F}}$ and $E_{\text{MPE,avg}}$ consequently, for this example $E_{\text{MPE,train,F}}$ is always the most restrictive.

Amendment 1, page 11

Delete, the first four paragraphs on this page, i.e. delete all wording above the title **Single-diode group:**

Amendment 1, page 11, paragraph below first equation:

Delete the first sentence which begins "Since this value...".

Amendment 1, page 13, first paragraph after the heading **Horizontal two-diode group:**

Delete the third sentence which begins "The most restrictive...".

Amendment 1, page 13, first paragraph after the heading **Vertical two-diode group:**

Delete the third sentence which begins "The most restrictive...".

Amendment 1, page 13, first paragraph after the heading **Four-diode group:**

Replace the third sentence which begins "The most restrictive ..."

by "Hence the correction factor is C_6 = 4/1,5 = 2,67."

Amendment 1, page 15, first paragraph after the heading **One row of ten diodes:**

Delete the third sentence which begins "In this case the most restrictive ...".

Amendment 1, page 15, first paragraph after the heading **One row of ten diodes:**

Replace the fourth sentence as follows:

Hence the correction factor is C_6 = 15,3/1,5 = 10,2.

Amendment 1, page 15, first equation after the heading **One row of ten diodes:**

Replace as follows:

$$E_{\text{MPE,ten}} = E_{\text{MPE,train,F}} = 8{,}28 \times 10{,}2\ \text{W}\cdot\text{m}^{-2} = 84{,}5\ \text{W}\cdot\text{m}^{-2}$$

Amendment 1, page 15, last sentence below the heading **One row of ten diodes:**

Replace the last sentence as follows:

At a distance of 1 m, the hazard factor is 1 800/84,5 = 21,3.

Amendment 1, page 15, first paragraph after the heading **Twenty-diode group:**

Replace the third and fourth sentences as follows:

The average is 16 mrad, the correction factor is C_6 = 16/1,5 = 10,7 and the applicable MPE is as follows:

Amendment 1, page 15, first equation after the heading **Twenty-diode group:**

Replace the equation as follows:

$$E_{\mathrm{MPE,twenty}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 10{,}7\ \mathrm{W{\cdot}m^{-2}} = 88{,}3\ \mathrm{W{\cdot}m^{-2}}$$

Amendment 1, page 15, second and third paragraphs after the heading **Twenty-diode group:**

Replace the text as follows:

At a distance of 1 m, the hazard factor is 3 600/88,3 = 40,7. This is the largest hazard factor found in this example.

It can be shown by calculations that other groups, such as three horizontally adjacent diodes, six adjacent diodes (2 × 3), etc., give hazard factors smaller than 40,7. Therefore 40,7 is the hazard factor to be used to evaluate the hazard of this array.

Amendment 1, page 15, second paragraph and equation after the heading **Additional remarks:**

Replace the paragraph and equation as follows:

In this new situation, the angular subtense that is to be used for the entire array is (2,8 + 56,2)/2 mrad = 29,5 mrad, and the most restrictive MPE is given by $E_{\mathrm{MPE,train,F}}$. Hence, the correction factor C_6 = 29,5/1,5 = 19,7 and the applicable MPE is as follows:

$$E_{\mathrm{MPE,twenty}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 19{,}7\ \mathrm{W{\cdot}m^{-2}} = 163\ \mathrm{W{\cdot}m^{-2}}$$

Amendment 1, page 15, last sentence on the page:

Replace as follows:

The hazard factor of the entire array is 3 600/163 = 22,1.

Amendment 1, page 17, first paragraph:

Replace the first sentence as follows:

Thus, C_6 = 11,5/1,5 = 7,67

Amendment 1, page 17, first equation:

Replace as follows:

$E_{\mathrm{MPE,eight}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 7{,}67\ \mathrm{W{\cdot}m^{-2}} = 63{,}5\ \mathrm{W{\cdot}m^{-2}}$.

Amendment 1, page 17, first paragraph after the second equation:

Replace the paragraph as follows:

The hazard factor of this grouping is 1 440/63,5 = 22,7. Since 22,7 is the greatest value, it is to be considered as the hazard factor for this array.

Amendment 1, page 17, first paragraph after the heading **Required optical density:**

Replace the paragraph as follows:

To protect the viewer at a distance of 1 m, an attenuation factor of 40,7 would be required in a protective filter. An optical density of 1,7 corresponds to an attenuation factor of 50 and would provide adequate protection from this laser at a distance of 1 m.

Amendment 1, page 19, first paragraph, second line:

Replace "8.2 j" *by* "8,4 d".

Amendment 1, page 19, second paragraph, third line:

Replace "286" *by* "122" *(in two places).*

Replace "2,46" *by* "2,1".

Amendment 1, page 19, fifth paragraph, third line:

Replace the line as follows:

OD = 2,1 – 0,15 = 1,95. Thus, an OD of 1,95 or more would provide protection for both aided

Amendment 1, pages 19 and 21

Delete the last section of the solution headed **Considerations on the pulse repetition frequency**

Page 131

Delete the title and text.

A.3 Maximum permissible exposures (MPE) – diffuse reflections and extended sources

Replace the existing text as follows:

Examples of extended source viewing are:

1) Laser radiation within the wavelength range 400 nm to 1 400 nm is reflected from a diffusing surface (apparent source).
2) The image formed on the retina of the eye by the diffuse reflection is larger than a certain minimum value of the retinal image, determined by the limiting angular subtense α_{min}, where α_{min} is equal to 1,5 mrad.

The limiting angular subtense α_{min} is measured at a distance of no less than 100 mm from the apparent source (see 8.4 c)).

Page 133

Example A.3-1

Replace, in two places, "point source" *by* "small source".

Page 135

Replace, in the first paragraph, the last two sentences and the following equation as follows:

Where the maximum angle of acceptance, α_{max}, is 0,1 rad corresponding to a solid angle, Ω, given by $\Omega \approx \pi\ (\alpha_{max}/2)^2 = 7{,}85 \times 10^{-3}$ sr

and the diffuse reflection MPE expressed as an integrated radiance is

$$L_{MPE} = (C_6/\Omega) \times H_{MPE,\ small\ src.} = (66{,}66\ /\ 7{,}85 \times 10^{-3}) \times H_{MPE,\ small\ src.}$$

$$L_{MPE} = 8{,}5 \times 10^3 \times H_{MPE,\ small\ src.}\ \mathrm{J \cdot m^{-2} \cdot sr^{-1}}$$

Replace in the second paragraph "point source" *by* "small source".

Example A.3-3

Replace, in three places, one in equation for r_{NOHD}, "point source" *by* "small source".

Page 137

Example A.4-1

Replace the question by the following:

Determine the small-source MPE for accidental, direct ocular exposure to the radiation from an argon laser (λ = 488 nm) operating at a frequency of F = 1 MHz with a pulse duration of $t = 10^{-8}$ s.

Replace the solution by the following:

As the laser is operating in the visible part of the spectrum and intentional viewing is not intended, an exposure duration limited by the blink reflex to T = 0,25 s will be used. If intentional viewing of radiation in the wavelength range 400 nm to 600 nm is intended for exposure durations of 1 s or more, then the photochemical ocular limit should be evaluated, in addition to the thermal limit, and the most restrictive gives the applicable MPE.

Subclause 13.3 includes three criteria which must be considered, and the most restrictive one applies to this evaluation. The value of C_6 is 1 in these calculations since the beam is emitted from a small source.

From 13.3a), the exposure from any single-pulse shall not exceed the single-pulse MPE. Thus, the radiant exposure for the time period of 10^{-8} s from table 6 is

$$H_{single} = 5 \times 10^{-3} \times C_6\ \mathrm{J \cdot m^{-2}} = 5 \times 10^{-3} \times 1\ \mathrm{J \cdot m^{-2}} = 5 \times 10^{-3}\ \mathrm{J \cdot m^{-2}}$$

From 13.3b), the average exposure for a pulse train of exposure duration T shall not exceed the MPE for a single pulse of exposure duration T. For the total 0,25 s exposure duration, table 6 limits the radiant exposure to

$$H_T = 18\ t^{0,75}\ C_6\ \text{J·m}^{-2} = 18 \times (0,25)^{0,75} \times 1\ \text{J·m}^{-2} = 6,36\ \text{J·m}^{-2}$$

Since there are $N = 2,5 \times 10^5$ pulses in the 0,25 s period, the average irradiance criteria results in a single pulse radiant exposure of

$$H_{\text{single-avg}} = H_T/N = 6,36 / 2,5 \times 10^5\ \text{J·m}^{-2} = 2,55 \times 10^{-5}\ \text{J·m}^{-2}$$

From 13.3c), the average exposure from pulses within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor C_5 (where $C_5 = N^{-1/4}$). The maximum exposure duration for which requirement c) should be applied is T_2 in the wavelength range 400 nm to 1 400 nm, where T_2 = 10 s for $\alpha \leq \alpha_{min}$.

Since the laser is operating at a high repetition rate, note 2 to 13.3c) is applicable. This requires that, if multiple pulses appear within the period of T_i (see table 9 for $T_i = 18 \times 10^{-6}$ s) they are counted as a single pulse to determine N and the radiant exposure of the individual pulses is added to be compared to the MPE of T_i. Hence, the effective pulse repetition frequency is:

$$F_E = 1/T_i = 1/(18 \times 10^{-6}) = 55,56\ \text{kHz}$$

The MPE for a pulse of duration T_i is given in table 6 as $5 \times 10^{-3}\ C_6\ \text{J·m}^{-2} = 5 \times 10^{-3}\ \text{J·m}^{-2}$.

The effective number of pulses in 0,25 s is:

$$N_E = T \times F_E = 0,25 \times 55,56 \times 10^3 = 1,39 \times 10^4$$

For $N_E = 1,39 \times 10^4$ pulses each of duration T_i in the 0,25 s period the radiant exposure under this criteria would be:

$$H_{\text{train}} = H_{\text{single-eff}} \times (N_E)^{-1/4} = 5 \times 10^{-3}\ (1,39 \times 10^4)^{-1/4} = 4,6 \times 10^{-4}\ \text{J·m}^{-2}$$

Conditions 13.3a) and 13.3b) are applicable to a pulse of energy, Q, while condition 13.3c) is applicable to a pulse of energy = $Q \times T_i \times F = 18 \times Q$. Hence, dividing H_{train} by 18 (to give $2,55 \times 10^{-5}$ J·m^{-2}) enables the three MPEs calculated from 13.3 to be compared. In this example criteria 13.3b) and 13.3c), which are equal, are the most restrictive; the single-pulse MPE for this system would be $2,55 \times 10^{-5}$ J·m^{-2}.

Example A.4-2, Solution

Replace, in the second paragraph, third line, "point source" *by* "small source".

Page 141

Replace the first sentence of the first paragraph as follows:

From 13.3b), the average exposure for a pulse train of exposure duration T shall not exceed the MPE for a single pulse of exposure duration T.

Replace the first sentence of the third paragraph as follows:

From 13.3c), the average exposure from pulses within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor C_5 (where $C_5 = N^{-1/4}$)

A.5 Nominal ocular hazard distance (NOHD)

Replace, in the last line of the note, the words in brackets, as follows:

(see 9.2 on measurements).

Page 143

Replace, in the second sentence of the paragraph between equations (3) and (4), "However, the following approach will lead to a slightly oversafe result:" *by* "However, the following approach will lead to an oversafe result:".

Definition of quantities below equation (5)

For the definition of the quantity A add a space between the V and the power 0,33.

Page 145

Modify the note as follows:

NOTE The output from lasers of Class 1, Class 1M, Class 2, Class 2M and Class 3R may be viewed via a diffusing screen or non-specular target through magnifying optics, provided that the criteria for unaided viewing of extended sources are satisfied and that the radiation is within the band 400 nm to 1 400 nm.

Example A.5-1

Replace, in the first sentence, the words "A laser has an output of 4 W, a beam divergence of 0,7 mrad and an exit beam diameter of 1 mm." *by* "A laser with a Gaussian beam profile has an output of 4 W, a beam divergence of 0,7 mrad and an exit beam diameter of 1 mm."

Page 147

Example A.5-4

Replace, in a), "65 m" *by* "60 m".

Page 147

Example A.5-4, Solution

Replace the second and following paragraphs as follows:

For an exposure duration between 10 s and 3 × 10⁴ s, the appropriate MPE is given in table 6 as one of three possibilities depending on the exposure duration, t, relative to the break point, T_2, and for $t > T_2$ on the value of α:

1st case: For an exposure duration $t \leq T_2$

$$H_{MPE} = 18\ t^{0,75}\ C_6\ \text{J·m}^{-2}$$

which is equivalent to

$$E_{\text{MPE}} = 18\ t^{-0,25}\ C_6\ \text{W·m}^{-2}$$

2nd case: For an exposure duration $t > T_2$ and $\alpha \leq 1{,}5$ mrad

$$E_{\text{MPE}} = 10\ \text{W·m}^{-2}$$

Thus, for this problem with an exposure duration of $t > T_2$ the MPE is constant and independent of exposure duration.

3rd case: For an exposure duration $t > T_2$ and $\alpha > 1{,}5$ mrad

$$E_{\text{MPE}} = 18\ T_2^{-0,25}\ C_6\ \text{W·m}^{-2}$$

NOTE All correction factors are listed in the notes to tables 1 to 4. The irradiance expressions are often a more convenient form for the solution of ranging problems.

This is a small-source type viewing condition; therefore, $\alpha \leq \alpha_{\text{min}}$, $C_6 = 1$ and $T_2 = 10$ s (it should be emphasized that the source size is never the diameter of the laser output beam unless the beam passes through a diffuser or the beam is emitted from a laser array).

This part of the problem is solved by equating the irradiance MPE expression given above with the irradiance at a range r expression (i.e., equation (1)), and solving for the exposure duration t. Thus, assuming that case 1 is valid (i.e., $t < T_2$), then the maximum exposure duration is obtained by solving the following expression for t:

$$E_{\text{MPE}} = 18\ t^{-0,25} = \frac{4\,P_{\text{o}}}{\pi\,(a + r\,\phi)^2}$$

$$18\ t^{-0,25} = \frac{4 \times 3 \times 10^{-3}}{\pi\,(0{,}013 + 60 \times 10^{-4})^2} = 10{,}58\ \ \text{W} \cdot \text{m}^{-2}$$

$$\text{Thus } t = \left(\frac{10{,}58}{18}\right)^{-4} = 8{,}38\ \text{s}$$

The exposure duration $t = 8{,}38$ s is less than T_2, so there is no reason to evaluate the second and third cases.

For b): The minimum range for safe viewing can be obtained by solving equation (3) for the nominal ocular hazard distance (NOHD). In this case, the exposure duration $t = 180$ s is used which is greater than T_2 and therefore case 2 applies where $E_{\text{MPE}} = 10\ \text{W·m}^{-2}$:

$$r_{\text{NOHD}} = \frac{1}{\phi} \times \left[\sqrt{\frac{4\,P_{\text{o}}}{\pi\,E_{\text{MPE}}}} - a\right]$$

$$r_{\text{NOHD}} = \frac{1}{10^{-4}} \times \left[\sqrt{\frac{4 \times\ 3 \times 10^{-3}}{\pi \times 10}} - 0{,}013\right] = 65{,}4\ \text{m}$$

Page 151

Example A.5-5

Replace the fourth line of the question as follows: "peak power per pulse P_p is 30 W".

Replace the fifth line of the question as follows: "energy per pulse Q_p is 6×10^{-7} J;"

Replace the last two lines of the question as follows:

Assuming the laser has a Gaussian beam profile, assess the NOHD for this instrument

a) for viewing by the unaided eye, and

b) when using 8 × 50 binoculars.

Example A.5-5, Solution

Replace the first sentence of the second paragraph as follows:

In this example, it is assumed that the subtense α is less than α_{min} and for a small source C_6 = 1.

Multiple-pulse assessment

Replace the text as follows:

From 13.3c), the average exposure from pulses within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor C_5 (where $C_5 = N^{-1/4}$). The maximum exposure duration for which requirement c) should be applied is T_2 in the wavelength range 400 nm to 1 400 nm, where T_2 = 10 s for $\alpha \le \alpha_{min}$. Hence:

$$H_{MPE,\ single} = H_{MPE} = 5 \times 10^{-3} \times 2{,}55 = 1{,}275 \times 10^{-2}\ \mathrm{J{\cdot}m^{-2}}$$

$$H_{MPE,\ train} = H_{MPE,\ single}\ N^{-1/4} = 1{,}275 \times 10^{-2} \times (10 \times 300)^{-1/4}\ \mathrm{J{\cdot}m^{-2}}$$

$$H_{MPE,\ train} = 0{,}135 \times 1{,}275 \times 10^{-2} = 1{,}72 \times 10^{-3}\ \mathrm{J{\cdot}m^{-2}}$$

From the value of $H_{MPE,\ train}$ the corresponding value in irradiance can be derived:

$$E_{MPE,\ train} = \frac{H_{MPE,\ train}}{t_p} = \frac{1{,}72 \times 10^{-3}}{20 \times 10^{-9}} = 8{,}61 \times 10^{4}\ \mathrm{W \cdot m^{-2}}$$

To find the range at which this threshold for a reduced single pulse is exceeded, the range equation of the previous example is used:

$$r_{NOHD} = \frac{1}{\phi} \times \left[\sqrt{\frac{4\,P_p}{\pi \times E_{MPE,\ train}}} - a \right]$$

$$r_{NOHD} = \frac{1}{0{,}01} \times \left[\sqrt{\frac{4 \times 30}{\pi \times 8{,}61 \times 10^{4}}} - 0{,}055 \right] = -\,3{,}39\ \mathrm{m}$$

This value of r_{NOHD} is negative. Thus, according to the multiple-pulse assessment, it is safe to suffer exposure to this laser beam at any range, on the basis of the reduced single-pulse value.

Average exposure assessment

Replace the text as follows:

The MPE for an exposure duration of 100 s is obtained from table 6. Since $\alpha \leq 1{,}5$ mrad $T_2 = 10$ s, therefore the condition $t > T_2$ applies:

$$E_{\text{MPE, avg}} = 10\ C_4\ C_7\ \text{W·m}^{-2}$$

where $C_4 = 2{,}55$ and $C_7 = 1$.

The limit for the average irradiance of the pulse train (see 13.3) is the following:

$$E_{\text{MPE, avg}} = 10 \times 2{,}55 \times 1 = 25{,}5\ \text{W·m}^{-2}$$

Page 155

Replace third equation as follows:

$$r_{\text{NOHD}} = \frac{1}{0{,}01} \times \left[\sqrt{\frac{4 \times 1{,}8 \times 10^{-4}}{\pi \times 25{,}5}} - 0{,}055 \right] = 5{,}2\ \text{m}$$

b) Binocular viewing condition

Replace the two equations of this item and the sentence between the two equations as follows:

$$E_{\text{MPE}}(\text{binocular}) = G^{-2} \times E_{\text{MPE}}(\text{unaided}) = 1{,}96 \times 10^{-2} \times 8{,}61 \times 10^{4} = 1{,}69 \times 10^{3}\ \text{W·m}^{-2}$$

The range from the laser at which the single-pulse irradiance falls to $1{,}69 \times 10^3$ W·m^{-2} is given by

$$r_{\text{NOHD}} = \frac{1}{0{,}01} \times \left[\sqrt{\frac{4 \times 30}{\pi \times 1{,}69 \times 10^{3}}} - 0{,}055 \right] = 9{,}5\ \text{m}$$

In the last line of the fifth paragraph, on page 157, change "14,6 m" *to* "9,5 m".

Page 157

Example A.5-6

Replace the third line of the question as follows: peak power per pulse $P_p = 1{,}5$ MW;

Replace the fourth line of the question as follows: energy per pulse $Q_p = 45$ mJ;

Example A.5-6 Solution, a) Unaided eye condition

Replace the text of this item as follows:

a) Unaided eye condition

The pulse width t_p can be calculated from the condition $P_p \times t_p = Q_p$ by $1{,}5 \times 10^6 \times t_p = 45 \times 10^{-3}$

giving $t_p = 30$ ns (i.e. $10^{-9} < t_p < 5 \times 10^{-5}$ s). The pulse repetition frequency F is 12/60 = 0,2 Hz.

In this example, it is assumed that $\alpha \le \alpha_{min}$ and for a small source C_6 = 1. If there is no intentional viewing, the exposure duration to be used is 100 s; during this time, the number of pulses is

$$N = F \times t = 0{,}2 \text{ Hz} \times 100 \text{ s} = 20$$

The intrabeam MPE is taken as the most restrictive calculated from the application of 13.3.

Single-pulse assessment (condition 13.3a))

From table 6, the MPE for a single-pulse exposure from this laser is

$$H_{\text{MPE}} = 5 \times 10^{-2}\ C_6\ C_7 \text{ J·m}^{-2}$$

where C_6 = 1 and C_7 = 1, therefore

$$H_{\text{MPE, single}} = 5 \times 10^{-2} \text{ J·m}^{-2}$$

Average irradiance assessment (condition 13.3b))

From table 6, the MPE for the exposure duration of 100 s is

$$H_{\text{MPE}} = 90 \times t^{0,75}\ C_6\ C_7 \text{ J·m}^{-2}$$

where C_6 = 1 and C_7 = 1. There are 20 pulses in 100 s, therefore the average MPE per pulse is

$$H_{\text{MPE, average}} = \frac{90 \times 100^{0,75}}{20} = 142 \text{ J} \cdot \text{m}^{-2}$$

Multiple-pulse assessment (condition 13.3c))

The maximum exposure duration for which requirement c) should be applied is T_2 in the wavelength range 400 nm to 1 400 nm, where T_2 = 10 s for $\alpha \le \alpha_{min}$. Therefore, the correction factor $N^{-1/4} = (10 \times 0{,}2)^{-1/4} = 0{,}84$ is used to calculate $H_{\text{MPE, train}}$:

$$H_{\text{MPE, train}} = H_{\text{MPE, single}}\ N^{-1/4} = 5 \times 10^{-2} \times 0{,}84 = 4{,}2 \times 10^{-2} \text{ J·m}^{-2}$$

The conclusion is that condition 13.3c) produces the most restrictive MPE per pulse and therefore, $H_{\text{MPE}} = 4{,}2 \times 10^{-2}$ J·m^{-2} for intrabeam viewing. The range equation of the previous example can be used to calculate r_{NOHD}; however, because the mode structure of this solid-state laser is not specified, the pulse energy should be increased by a factor 2,5. Therefore,

$$r_{\text{NOHD}} = \frac{1}{\phi} \times \left[\sqrt{\frac{4 \times 2{,}5 \times Q}{\pi \times H_{\text{MPE, train}}}} - a \right]$$

$$r_{\text{NOHD}} = \frac{1}{10^{-3}} \times \left[\sqrt{\frac{4 \times 2{,}5 \times 45 \times 10^{-3}}{\pi \times 4{,}2 \times 10^{-2}}} - 0{,}01 \right] = 1{,}84 \text{ km}$$

The NOHD for the rangefinder is therefore 1,84 km.

If a 10 % transmission filter is fitted to the output aperture of this instrument, the NOHD is reduced. In this case, using the previous equation for r_{NOHD} the energy per pulse must be modified by the factor 0,1, to take into account the effect of the 10 % filter. The modified NOHD is therefore given by

$$r_{\mathrm{NOHD}} = \frac{1}{10^{-3}} \times \left[\sqrt{\frac{4 \times 2{,}5 \times 0{,}1 \times 45 \times 10^{-3}}{\pi \times 4{,}2 \times 10^{-2}}} - 0{,}01 \right] = 574 \text{ m}$$

Example A.5-6, Solution, b) Binocular viewing condition

Replace, on page 161, the second equation as follows:

$$r_{\mathrm{NOHD}} = \frac{1}{10^{-3}} \times \left[\sqrt{\frac{4 \times 2{,}5 \times 45 \times 10^{-3}}{\pi \times 1{,}96 \times 10^{-2} \times 4{,}2 \times 10^{-2}}} - 0{,}01 \right] = 13{,}18 \text{ km}$$

Replace, on page 161, the last line of the third paragraph as follows: "distances less than 13,18 km from the laser."

Page 163

A.6 Accessible emission limits for diverging beam, point-type sources

Replace the first line of the second paragraph as follows:

"All of the examples in clause A.6 assume that the beam emerging from the small. . ."

Replace the last line of the second paragraph as follows:

"described; therefore, the time base is 100 s (see 8.4 e))."

Page 165

Example A.6-1

Replace the second sentence of the question as follows:

If the transmitter is operated in CW mode, what is the maximum total power allowed for classification as

a) Class 1, and

b) Class 1M.

Example A.6-1, Solution

Replace the text by the following new text:

a) Class 1

The time base used for a Class 1 system is 100 s. Table 1 indicates that the AEL for emission in the wavelength range 700 nm to 1 050 nm with an exposure duration in the range from 10 s to 3×10^4 s depends on the value of T_2 given in the notes to tables 1 to 4 by the expression:

$$T_2 = 10 \times 10^{(\alpha - 1{,}5 \text{ mrad})/98{,}5} \text{ s}$$

Since we have a small source $\alpha \leq \alpha_{min}$ then T_2 = 10 s and $t > T_2$. From table 1

$$P_{AEL} = 3{,}9 \times 10^{-4}\ C_4\ C_7 \text{ W}$$

where

C_4 = 2, C_7 = 1 and hence P_{AEL} = 7,8 × 10^–4^ W

The measurement specifications given in 9.3 indicate that the P_{AEL} for a source that failed condition 2 of table 10 must be compared to the power collected though a 7 mm aperture at a distance of 14 mm from the source. In this example, the beam diameter at the measurement distance is

$$d_{63} = \frac{2\,r\,NA}{1{,}7} = \frac{2 \times 14 \times 0{,}3}{1{,}7} = 4{,}94 \text{ mm}$$

and all of the emitted power will pass through the 7 mm measurement aperture. Therefore, the maximum Class 1 output power is the P_{AEL} value of 0,78 mW.

This maximum total output power value is for CW operation. In the case of a digital transmission with a duty cycle of 50 %, the pulse power of a single pulse in the train may be up to twice the CW power derived above (depending on the characteristics of the pulse train (see 8.4f)) repetitively pulsed or modulated lasers).

b) Class 1M

If the level of radiation as determined according to table 10 is larger than the AEL of Class 1 for condition 1 or condition 2 and less than the AEL of Class 3B, but the level of radiation measured with an aperture stop of 7 mm diameter at a distance of 100 mm from the apparent source is less than or equal to the AEL of Class 1, the laser product is assigned to Class 1M.

In this example, the beam diameter at the measurement distance of 100 mm is

$$d_{63} = \frac{2\,r\,NA}{1{,}7} = \frac{2 \times 100 \times 10^{-3} \times 0{,}3}{1{,}7} = 35{,}3 \text{ mm}$$

and the fraction of the total emitted power that passes through the measurement aperture is

$$P_a = \eta\, P_o = \left[1 - e^{-\left(\frac{d_a}{d_{63}}\right)^2}\right] P_o = \left[1 - e^{-\left(\frac{7}{35{,}3}\right)^2}\right] P_o = 0{,}039\, P_o$$

The maximum Class 1M output power is obtained by equating P_a with P_{AEL}:

$$P_{o,max} = \frac{P_{AEL}}{\eta} = \frac{0{,}78}{0{,}039} = 20 \text{ mW}$$

Since this is less than the P_{AEL} (500 mW) of Class 3B. Therefore, in this example, the maximum Class 1M output power is 20 mW.

Page 167

Example A.6-2

Replace the last sentence of the question as follows:

Determine (a) Class I, (b) Class IM and (c) Class 3R power limits and determine which are applicable.

Example A.6-2, Solution

Replace, in two places, in the first paragraph "9.4" *by* "8.4".

Replace the rest of the text as follows:

a) Class 1

The time base used for a Class 1 system is 100 s. Table 1 indicates that the AEL for emission in the wavelength range 700 nm to 1 050 nm with an exposure duration in the range from 10 s to 3×10^4 s depends on the value of T_2 given in the notes to tables 1 to 4 by the expression:

$$T_2 = 10 \times 10^{(\alpha - 1{,}5\ \mathrm{mrad})/98{,}5}\ \mathrm{s}$$

Since we have a small-source $\alpha \leq \alpha_{min}$ then T_2 = 10 s and $t > T_2$. From table 1

$$P_{AEL} = 3{,}9 \times 10^{-4}\ C_4\ C_7\ \mathrm{W}$$

where $C_4 = 10^{0{,}002(\lambda - 700)} = 1{,}445$ and $C_7 = 1$ therefore

$$P_{AEL} = 3{,}9 \times 10^{-4} \times 1{,}445 \times 1 = 0{,}56\ \mathrm{mW}$$

The measurement specifications given in 9.3 indicate that the P_{AEL} for a source that failed condition 2 of table 10 must be compared to the power collected though a 7 mm aperture at a distance of 14 mm from the source. In this example, the beam diameter at the measurement distance is

$$d_{63} = \frac{2\,r\,NA}{1{,}7} = \frac{2 \times 14 \times 0{,}16}{1{,}7} = 2{,}63\ \mathrm{mm}$$

The fraction of the total emitted power (P_a) that passes through a 7 mm measurement aperture 14 mm from the source is

$$P_a = \eta\, P_o = \left[1 - e^{-\left(\frac{d_a}{d_{63}}\right)^2}\right] P_o = \left[1 - e^{-\left(\frac{7}{2{,}63}\right)^2}\right] P_o \approx P_o$$

Therefore, the maximum emitted power for Class 1 is 0,56 mW.

b) Class 1M

If the level of radiation as determined according to table 10 is larger than the AEL of Class 1 for condition 1 or condition 2 and less than the AEL of Class 3B, but the level of radiation measured with an aperture stop of 7 mm diameter at a distance of 100 mm from the apparent source is less than, or equal to, the AEL of Class 1, the laser product is assigned to Class 1M.

In this example, the beam diameter at the measurement distance of 100 mm is

$$d_{63} = \frac{2\,r\,NA}{1{,}7} = \frac{2 \times 100 \times 0{,}16}{1{,}7} = 18{,}82\ \mathrm{mm}$$

and the fraction of the total emitted power that passes through the measurement aperture is

$$P_a = \left[1 - e^{-\left(\frac{7}{18{,}82}\right)^2}\right] P_o = 0{,}13\ P_o$$

Thus, the maximum emitted power corresponding to Class 1M ($P_{o,max}$) is

$$P_{o,max} = \frac{P_{AEL}}{\eta} = \frac{0,56}{0,13} = 4,33\ \text{mW}$$

Since this is less than 500 mW (the Class 3B AEL), the maximum Class 1M emitted power is 4,33 mW.

c) Class 3R

The Class 3R limits are 5 times Class 1. For this example, that would be

$$P_{\text{Class 3R}} = 5 \times (P_{\text{Class 1}}) = 2,80\ \text{mW}$$

Since Class 1M > Class 3R, there is no Class 3R. Any power over 4,33 mW but less than 500 mW for this example, would be defined as Class 3B.

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Example A.6-3

Replace items (a) and (b) in the last three lines of the question as follows:

(a) Determine the maximum average output power for Class IM and Class 3R AELs.

(b) Determine the maximum average output power for Class IM and Class 3R AELs if the emitting wavelength is 1 550 nm.

Example A.6-3 Solution

Replace the text as follows:

As in example A.6-2 the output can be treated like a CW emission at a power level equal to the average emitted power due to the high data transmission rate and the balanced code.

a) 1 300 nm

At a wavelength of 1 300 nm and a time base of 100 s, the maximum average emitted power for Class 1M and Class 3R is found as follows:

Class 1M

The time base used for a Class 1 system is 100 s. Table 1 indicates that the AEL for emission in the wavelength range 1 050 nm to 1 400 nm with an exposure duration in the range from 10 s to 3 × 10⁴ s depends on the value of T_2 given in the notes to tables 1 to 4 by the expression:

$$T_2 = 10 \times 10^{(\alpha - 1,5\ \text{mrad})/98,5}\ \text{s}$$

Since we have a small-source $\alpha \le \alpha_{min}$ then T_2 = 10 s and $t > T_2$. From table 1:

$$P_{AEL} = 3,9 \times 10^{-4}\ C_4\ C_7\ \text{W}$$

where C_4 = 5 and C_7 = 8 therefore

P_{AEL} = 15,6 mW

This aperture power is then corrected for the aperture coupling loss with the coupling parameter η (defined in equation (3)) to obtain the maximum emitted power level for the AEL condition. The coupling parameter depends upon the diameter of the beam at the distance the aperture is located from the source (100 mm). For the single-mode fibre in this example the beam diameter is given by equation (2):

$$d_{63} = \frac{2\sqrt{2}\, r\, \lambda}{\pi\, \omega_o} = \frac{2 \times \sqrt{2} \times 100 \times 1\ 300}{\pi \times 10} = 11{,}7\ \text{mm}$$

The fraction of the total emitted power (P_a) that passes through a 7 mm measurement aperture 100 mm from the source is

$$P_a = \eta\, P_o = \left[1 - e^{-\left(\frac{d_a}{d_{63}}\right)^2}\right] P_o = \left[1 - e^{-\left(\frac{7}{11{,}7}\right)^2}\right] P_o = 0{,}30\, P_o$$

The maximum emitted power corresponding to Class 1M ($P_{o,max}$) is

$$P_{o,max} = \frac{P_{AEL}}{\eta} = \frac{15{,}6}{0{,}3} = 51{,}8\ \text{mW}$$

Because 51,8 mW is less than 500 mW, Class 1M = 51,8 mW

Class 3R

At a wavelength of 1 300 nm and a time base of 100 s table 3 gives the small source ($\alpha \le \alpha_{min}$) AEL expression for total emitted power as

$$P_{AEL} = 2 \times 10^{-3}\, C_4\, C_7\ \text{W}$$

where C_4 = 5 and C_7 = 8, therefore

$P_{AEL} = 2 \times 10^{-3} \times 5 \times 8 = 80$ mW

Due to the small beam divergence of a single-mode fibre, essentially 100 % of the emitted power is coupled into a 7 mm aperture at 14 mm from the source. Hence, the aperture coupling parameter η = 1 and the maximum average power level with respect to the total power condition can be equated with the AEL value (i.e., $P_{max} = P_{AEL}$).

Because 80 mW > 51,8 mW, Class 3R exists for this example. Therefore, for this example, the product can be any of the following classes based on the output power: Class 1, Class 1M, Class 3R, Class 3B or Class 4.

b) 1 550 nm

Class 1M

If the same system is operated at 1 550 nm, then the procedure for performing the calculations is the same except that the AEL expression and apertures associated with the 1 550 nm wavelength are used.

Since we have a small-source $\alpha \le \alpha_{min}$ and t = 100 s, then from table 1

$$P_{AEL} = 10\ \text{mW}$$

The beam diameter at 100 mm is

$$d_{63} = \frac{2\sqrt{2}\,r\,\lambda}{\pi\,\omega_o} = \frac{2\times\sqrt{2}\times 100\times 1550}{\pi\times 10} = 13{,}95\ \text{mm}$$

The fraction of the total emitted power (P_a) that passes through a 3,5 mm measurement aperture 100 mm from the source is

$$P_a = \eta\,P_o = \left[1 - e^{-\left(\frac{d_a}{d_{63}}\right)^2}\right] P_o = \left[1 - e^{-\left(\frac{3{,}5}{13{,}95}\right)^2}\right] P_o = 0{,}061\ P_o$$

The maximum emitted power corresponding to Class 1M ($P_{o,max}$) is

$$P_{o,max} = \frac{P_{AEL}}{\eta} = \frac{10}{0{,}061} = 164\ \text{mW}$$

Since $P_{o,max}$ is more than five times the Class 1 AEL, there is no Class 3R for this product.

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Replace the existing annex B by the following new annex B:

Annex B
(informative)

Biophysical considerations

B.1 Anatomy of the eye

See figure B.1.

Figure B.1(A)

Diagram of the external features of a left eye. The gap between the overlying lids limits the field-of-view (FOV) of the eye to an almond shape. The main features of the front of the eye are labelled, and dotted lines and arrow heads relate them to the section through the eye.

Figure B.1(B)

A diagrammatic horizontal section of a left eye. The eye is divided into two parts, the front or anterior chamber which is bounded by the cornea, the iris, and the lens and the back or posterior eye cup which is bounded by the retina and contains the gel-like vitreous humour.

Figure B.1(C)

The inside of an intact eye seen through an ophthalmoscope. This instrument directs a beam of light through the pupil and illuminates the inside of the eye and so allows it to be seen. The picture so viewed is referred to as the fundus. It looks reddish, but the major retinal vessels can be clearly seen. Other prominent features are the whitish optic disc, and the fovea. The fovea is a small depression in the retinal surface which may be more pigmented than the surrounding retina and is the area of most acute vision. The fovea is the centre of the macula; the macula is responsible for detailed vision.

Figure B.1(D)

The structure of the retina as seen in the cut surface of figure B.1(B) but magnified approximately 320 times larger than life. The retina consists of a series of layers of nerve cells which overlie the photosensitive rod and cone cells; i.e. light falling on the retinal surface has to pass through the layers of nerve cells before it reaches the photosensitive cells. Underneath the layer of rods and cones is a layer called the pigment epithelium which contains a brownish black pigment called melanin; and beneath this is a layer of fine blood vessels, the choriocapillaris. The final absorbing layer is the choroid, which contains both pigmented cells and blood vessels.

Figure B.1(E)

The structure of the foveal region magnified approximately 150 times. Here only cones are present. The nerve cells are displaced radially away from this area of most acute vision. The macular pigment, which absorbs strongly from 400 nm to 500 nm, is located in the fibre layer of Henle.

B.2 The effects of laser radiation on biological tissue

The mechanism by which laser radiation induces damage is similar for all biological systems and may involve interactions of heat, thermoacoustic transients, photochemical processes and non-linear effects. The degree to which any of these mechanisms is responsible for damage may be related to certain physical parameters of the irradiating source, the most important of which are wavelength, pulse duration, image size, irradiance and radiant exposure.

In general terms, in supra-threshold exposures the predominating mechanism is broadly related to the pulse duration of the exposure. Thus, in order of increasing pulse duration, the predominant effects in the following time domains are: nanosecond and sub-nanosecond exposures, acoustic transients and non-linear effects; from 1 ms to several seconds, thermal effects, and, in excess of 10 s, photochemical effects.

Laser radiation is distinguished from most other known types of radiation by its beam collimation. This, together with an initial high energy content, results in excessive amounts of energy being transmitted to biological tissues. The primary event in any type of laser radiation damage to a biological system is the absorption of optical radiation by that system. Absorption occurs at an atomic or molecular level and is a wavelength specific process. Thus, it is the wavelength that determines which tissue a particular laser is liable to damage.

Thermal effects. When sufficient radiant energy has been absorbed by a system its component molecules experience an increased vibration, and this is an increase in heat content. Most laser damage is due to the heating of the absorbing tissue or tissues. This thermal damage is usually confined to a limited area extending to either side of the laser energy absorbing site, and centred on the irradiating beam. Cells within this area show burn characteristics, and tissue damage primarily results from denaturation of protein. As indicated above, the occurrence of secondary damage mechanisms in laser impacts can be related to the time course of the tissue heating reaction which is directly related to the pulse duration (figure B.2) and the period of cooling. Thermochemical reactions occur during both the heating and cooling period, giving rise to a spot-size dependence of thermal injury. If a CW or long-pulse laser impulse is directed onto a tissue, then because of conduction, the area of the biological tissue experiencing a raised temperature is progressively increased. This spreading thermal front results in an increasing damage zone as more and more cells are raised above their thermal tolerance. The beam image size is also of great importance, as the degree of peripheral spread due to conduction is a function of the size as well as the temperature of the initial area of tissue heating. This type of thermal lesion is commonly seen on exposure to CW or long pulsed lasers, but also occurs with short pulses. For irradiated spot sizes of the order of 1 mm to 2 mm or less, the radial heat flow leads to a spot-size dependence of injury.

Photochemical effects. On the other hand, damaging effects can be the direct result of specific molecular absorption of a given light. This process is created by absorption of given light energy. Rather than releasing the energy, however, the species undergoes a chemical reaction unique to its excited state. This photochemical reaction is believed to be responsible for damage at low levels of exposure. By this mechanism, some biological tissues such as the skin, the lens of the eye, and in particular the retina may show irreversible changes induced by prolonged exposure to moderate levels of UV radiation and short-wavelength light. Such photochemically induced changes may result in damage to a system if the duration of irradiation is excessive, or if shorter exposures are repeated over prolonged periods. Some of the photochemical reactions initiated by laser exposure may be abnormal, or exaggerations of normal processes. Photochemical reactions generally follow the Law of Bunsen and Roscoe, and for durations of the order of 1 h to 3 h or less (where repair mechanisms come into play), the threshold expressed as a radiant exposure is constant over a wide range of exposure durations. The spot-size dependence, as occurs with thermal effects due to heat diffusion, does not exist.