BRITISH STANDARD

BS EN 60825-1:1994

Incorporating Amendment Nos. 1, 2 and 3

Safety of laser products —

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

The European Standard EN 60825-1:1994, with the incorporation of amendments A2:2001 and A1:2002, has the status of a British Standard

British Standards

Cooperating organizations

The European Committee for Electrotechnical Standardization (CENELEC), under whose supervision this European Standard was prepared, comprises the national committees of the following countries:

Austria	Italy
Belgium	Luxembourg
Denmark	Netherlands
Finland	Norway
France	Portugal
Germany	Spain
Greece	Sweden
Iceland	Switzerland
Ireland	United Kingdom

This British Standard, having been prepared under the direction of the Electrotechnical Sector Board, was published under the authority of the Standards Board and comes into effect on 15 December 1994

The following BSI references relate to the work on this standard:
Committee reference EEL/28
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Amendments issued since publication

Amd. No.	Date	Comments
9019	April 1996	
9505	June 1997	
13230	24 September 2002	Indicated by a sideline in the margin and see national foreword

Contents

National foreword

This British Standard has been prepared by Technical Committee EPL/76 (formerly EEL/28) and is the English language version of EN 60825:1992 *Safety of laser products — Part 1: Equipment classification, requirements and user's guide* including its corrigendum: 1995 and amendments A2:2001 and A1:2002, published by the European Committee for Electrotechnical Standardization (CENELEC). Please note that CENELEC amendment A11:1996 has been withdrawn. It is derived from IEC 60825-1 Edition 1.2:2001, which comprises edition 1:1993 consolidated by the incorporation of amendment 1:1997 and amendment 2:2001, published by the International Electrotechnical Commission (IEC), with the incorporation of IEC corrigendum June 2002 which deletes row 11, Technical report, of Table H.1.

Amendment No. 2 to this British Standard corrects the over-classification of extended laser sources (e.g. when applying this standard to light emitting diodes).

An amendment to IEC 60825-1:1993 is currently being considered which would have the effect of making it technically equivalent to this British Standard.

The foreword of EN 60825-1:1994 makes reference to the "date of withdrawal", dow, of the relevant national standard. In this case the relevant national standard is BS EN 60825:1992 which was withdrawn on 1996-03-01. Certificates and marks will not be awarded after that date with respect to the withdrawn British Standard. However, such certificates and marks, already awarded, may continue to apply to production until 2000-03-01.

BS EN 60825 consists of the following Parts:

— *Part 1: Equipment classification, requirements and user's guide;*
— *Part 2: Safety of optical fibre communication equipment systems.*

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 117 and a back cover.

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60825-1

March 1994

+ A11 October 1996

+ A1 July 2002

+ A2 March 2001

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Supersedes EN 60825:1991
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Descriptors: Laser products, radiation safety, equipment classification, requirements, user's guide

English version

Safety of laser products — Part 1: Equipment classification, requirements and user's guide

(includes amendments A2:2001 and A1:2002)
(IEC 60825-1:1993 – corrigendum 1994 + A2:2001 + corrigendum June 2002 – A1:2002)

Sécurité des appareils a laser —
Partie 1: Classification des matériels, prescriptions et guide de l'utilisateur
(inclut les amendements A2:2001 et A2:2002)
(CEI 60825-1:1993 + corrigendum 1994 + A2:2001 – corrigendum June 2002 + A1:2002)

Sicherheit von Laser-Einrichtungen —
Teil 1: Klassifizierung von Anlagen, Anforderungen und Benutzer-Richtlinien
(enthält Änderungen A2:2001 und A1:2002)
(IEC 60825-1:1993 + corrigendum 1994 + A2:2001 + corrigendum June 2002 + A1:2002)

This European Standard was approved by CENELEC on 1993-09-22. Amendment A2 was approved by CENELEC on 2001-01-01 and amendment A1 was approved by CENELEC on 2002-07-02. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Ref. No. EN 60825-1:1994 + A2:2001 + A1 2002 E

Foreword

The text of documents 76(CO)28 & 28B, as prepared by IEC Technical Committee 76, Laser equipment, was submitted to the IEC-CENELEC parallel vote in November 1992 and was approved by CENELEC as amendment A2 to EN 60825:1991 on 1993-09-22.

In November 1993, IEC published the first edition of IEC 825-1.

Upon confirmation by CLC/TC 76 that

— IEC 825-1:1993 is equivalent to IEC 825:1984 + A1:1990 + documents 76(CO)28 & 28B;

— the common modifications accepted for EN 60825:1991 (IEC 825:1984 + A1:1990) are covered by this new IEC publication;

The Permanent Delegates of the Technical Board of CENELEC have confirmed the ratification of IEC 825-1:1993 as EN 60825-1.

The following dates were fixed:

— latest date of publication of an identical national standard	(dop) 1995-03-01
— latest date of withdrawal of conflicting national standards	(dow) 1996-03-01

For products which have complied with EN 60825:1991 before 1996-03-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 2000-03-01.

Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given only for information.

In this standard, Annex ZA is normative and Annex A, Annex B, Annex C, Annex D, Annex E and Annex F are informative.

Please note that amendment A11 has been withdrawn.

Foreword to amendment A2

The text of document 76/220/FDIS, future amendment 2 to IEC 60825-1:1993, prepared by IEC TC 76, Optical radiation safety and laser equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A2 to EN 60825-1:1994 on 2001-01-01.

The following dates were fixed:

— latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement	(dop) 2001-11-01
— latest date by which the national standards conflicting with the amendment have to be withdrawn	(dow) 2004-01-01

Foreword to amendment A1

The text of amendment 1:1997 to the International Standard IEC 60825-1:1993, prepared by IEC TC 76, Optical radiation safety and laser equipment, was approved by CENELEC as amendment A1 to EN 60825-1:1994 on 2002-07-02 without any modification.

This amendment A1 replaces A11:1996 to EN 60825-1:1994.

The following dates were fixed:

— latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement	(dop) 2003-07-01
— latest date by which the national standards conflicting with the amendment have to be withdrawn	(dow) 2004-01-01

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SAFETY OF LASER PRODUCTS –

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

Section One – General

1 Scope and object

1.1 Scope

IEC 60825-1 is applicable to safety of laser products. For convenience it is divided into three separate sections: Section One (General) and the annexes; Section Two (Manufacturing requirements); and Section Three (User's guide*).

A laser product may consist of a single laser with or without a separate power supply or may incorporate one or more lasers in a complex optical, electrical, or mechanical system. Typically, laser products are used for demonstration of physical and optical phenomena; materials processing; data reading and storage; transmission and display of information; etc. Such systems have found use in industry, business, entertainment, research, education and medicine. However, laser products which are sold to other manufacturers for use as components of any system for subsequent sale are not subject to IEC 60825-1, since the final product will itself be subject to this standard.

Throughout this part 1 light emitting diodes (LED) are included whenever the word "laser" is used. See also annex G which describes information which should be provided by manufacturers of LEDs.

Any laser product or LED product is exempt from all further requirements of this part 1 if

– classification by the manufacturer according to clauses 3, 8 and 9 shows that the emission level does not exceed the AEL of Class 1 under all conditions of operation, maintenance, service and failure, and
– it does not contain an embedded laser or embedded LED.

In addition to the hazards resulting from laser radiation, laser equipment may also give rise to other hazards such as fire and electric shock.

This part 1 describes the minimum requirements.

Where a laser system forms a part of equipment which is subject to another IEC product safety standard (e.g. for medical equipment (IEC 60601-2-22), IT equipment (IEC 60950), audio and video equipment (IEC 60065), equipment for use in hazardous atmospheres), this part 1 will apply in accordance with the provisions of IEC Guide 104**, for hazards resulting from laser radiation.

However, if the laser system is operable when removed from the equipment, all the requirements of this part 1 will apply to the removed unit.

If no product safety standard is applicable, then IEC 61010-1 shall apply.

* Some countries have requirements which differ from Section Three of this part 1. Therefore, contact the appropriate national agency for these requirements.

** IEC Guide 104:1984, *Guide to the drafting of safety standards, and the role of Committees with safety pilot functions and safety group functions.*

It gives guidance to IEC technical committees and to writers of specifications concerning the manner in which safety publications should be drafted.

This guide does not constitute a normative reference but reference to it is given for information only.

The MPE (maximum permissible exposure) values of this part 1 were developed for laser radiation and do not apply to collateral radiation.

However, if a concern exists that accessible collateral radiation might be hazardous, the laser MPE values may be applied to conservatively evaluate this risk.

The MPE values shall not be applicable to patient exposure to laser radiation for the purpose of medical treatment.

NOTE Annexes A to D have been included for purposes of general guidance and to illustrate many typical cases. However, the annexes must not be regarded as definitive or exhaustive and reference should always be made to the appropriate clause(s) in Sections One to Three.

1.2 Object

1.2.1 To protect persons from laser radiation in the wavelength range 180 nm to 1 mm* by indicating safe working levels of laser radiation and by introducing a system of classification of lasers and laser products according to their degree of hazard.

1.2.2 To lay down requirements for both user and manufacturer to establish procedures and supply information so that proper precautions can be adopted.

1.2.3 To ensure adequate warning to individuals of hazards associated with accessible radiation from laser products through signs, labels and instructions.

1.2.4 To reduce the possibility of injury by minimizing unnecessary accessible radiation and to give improved control of the laser radiation hazards through protective features and provide safe usage of laser products by specifying user control measures.

1.2.5 To protect persons against other hazards resulting from the operation and use of laser products.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60825. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60825 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60027-1:1992, *Letter symbols to be used in electrical technology – Part 1: General*
Amendment 1, 1997

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

IEC 60601-2-22:1995, *Medical electrical equipment – Part 2: Particular requirements for the safety of diagnostic and therapeutic laser equipment*

IEC 60825-2:2000, *Safety of laser products – Part 2: Safety of optical fibre communication systems*

IEC 61010-1:2001, *Safety requirements for electrical equipment for measurement, control and laboratory use – Part 1: General requirements*

IEC 61040:1990, *Power and energy measuring detectors, instruments and equipment for laser radiation*

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

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* In this part 1, the wavelength range λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$ (e.g. 180 nm to 1 mm means 180 nm $\leq \lambda <$ 1 mm).

3 Definitions*

For the purposes of this part of IEC 60825, the following definitions apply.

3.1
access panel
a part of the protective housing or enclosure which provides access to laser radiation when removed or displaced.

3.2
accessible emission limit (AEL)
the maximum accessible emission level permitted within a particular class

3.3
administrative control
safety measures of a non-engineering type such as: key supervision, safety training of personnel, warning notices, count-down procedures, and range safety controls

3.4
alignment laser product
the laser product designed, manufactured, intended or promoted for one or more of the following uses:

a) determining and delineating the form, extent or position of a point, body or area by taking angular measurements;
b) positioning or adjusting parts in relation to one another;
c) defining a plane, level, elevation or straight line.

3.5
alpha min. (α_{min})
see angular subtense (3.7)

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

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* Arranged here for convenience in English alphabetical order. Departures from IEC 60050(845) are intentional and are indicated. Reference is made to the definition number in Chapter 845 of IEC 60050.

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.

3.8
aperture, aperture stop
an aperture is any opening in the protective housing or other enclosure of a laser product through which laser radiation is emitted, thereby allowing human access to such radiation

An aperture stop is an opening serving to define the area over which radiation is measured.

3.9
apparent source
the real or virtual object that forms the smallest possible retinal image

NOTE This definition is used to determine the location of the apparent origin of laser radiation in the wavelength range of 400 nm to 1 400 nm, with the assumption of the apparent source being located in the eye's range of accommodation (≥100 mm). In the limit of vanishing divergence, i.e. in the case of an ideally collimated beam, the location of the apparent source goes to infinity.

The concept of an apparent source is used in the extended wavelength region 302,5 nm to 4 000 nm since focusing by conventional lenses might be possible in that region.

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

3.11
beam attenuator
a device which reduces the laser radiation to or below a specified level

3.12
beam diameter (beam width)
the beam diameter d_u at a point in space is the diameter of the smallest circle which contains u % of the total laser power (or energy). For the purpose of this standard d_{63} is used

NOTE In the case of a Gaussian beam, d_{63} corresponds to the point where the irradiance (radiant exposure) falls to 1/e of its central peak value.

3.13
beam divergence
the beam divergence is the far field plane angle of the cone defined by the beam diameter. If the beam diameters (see 3.10) at two points separated by a distance r are d_{63} and d'_{63} the divergence is given by:

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

SI unit: radian

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3.14
beam expander
a combination of optical elements which will increase the diameter of a laser beam

3.15
beam path component
an optical component which lies on a defined beam path (e.g. a beam steering mirror or a focusing lens)

3.16
beam stop
a device which terminates a laser beam path

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))

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)

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))

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

3.21
Class 3R and Class 3B laser products
any laser product which permits human access to laser radiation in excess of the accessible emission limits of Class 1 and Class 2 as applicable, but which does not permit human access to laser radiation in excess of the accessible emission limits of Classes 3R and 3B (respectively) for any emission duration and wavelength (see 8.2)

3.22
Class 4 laser product
any laser product which permits human access to laser radiation in excess of the accessible emission limits of Class 3B (see 8.2)

3.23
collateral radiation
any electromagnetic radiation, within the wavelength range between 180 nm and 1 mm, except laser radiation, emitted by a laser product as a result of, or physically necessary for, the operation of a laser

3.24
collimated beam
a "parallel" beam of radiation with very small angular divergence or convergence

3.25
continuous wave (CW)
the output of a laser which is operated in a continuous rather than pulsed mode. In this part 1, a laser operating with a continuous output for a period equal to or greater than 0,25 s is regarded as a CW laser

3.26
defined beam path
an intended path of a laser beam within the laser product

3.27
demonstration laser product
any laser product designed, manufactured, intended or promoted for purposes of demonstration, entertainment, advertising, display or artistic composition. The term "demonstration laser product" does not apply to laser products which are designed and intended for other applications, although they may be used for demonstrating those applications

3.28
diffuse reflection
change of the spatial distribution of a beam of radiation by scattering in many directions by a surface or medium. A perfect diffuser destroys all correlation between the directions of the incident and emergent radiation

NOTE This definition is different from IEV 845-04-47.

3.29
embedded laser product
in this part 1 a laser product which, because of engineering features limiting the accessible emissions, has been assigned a class number lower than the inherent capability of the laser incorporated

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

3.30
emission duration
the temporal duration of a pulse, of a train or series of pulses, or of continuous operation, during which human access to laser radiation could occur as a result of operation, maintenance or servicing of a laser product. 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

3.31
errant laser radiation
laser radiation which deviates from a defined beam path. Such radiation includes unwanted secondary reflections from beam path components, deviant radiation from misaligned or damaged components, and reflections from a workpiece

3.32
exposure time
the duration of a pulse, or series, or train of pulses or of continuous emission of laser radiation incident upon the human body. 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

3.33
extended source viewing
the viewing conditions whereby the apparent source at a distance of 100 mm or more subtends an angle at the eye greater than the limiting angular subtense (α_{min})

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.)

Examples are viewing of some diffuse reflections and of some laser diode arrays

3.34
fail safe
the design consideration in which failure of a component does not increase the hazard. In the failure mode the system is rendered inoperative or non-hazardous

3.35
fail safe safety interlock
an interlock which in the failure mode does not defeat the purpose of the interlock, for example an interlock which is positively driven into the OFF position as soon as a hinged cover begins to open, or before a detachable cover is removed, and which is positively held in the OFF position until the hinged cover is closed or the detachable cover is locked in the closed position

3.36
human access

a) Capability for a part of the human body to meet hazardous laser radiation either as emitted from an aperture, or capability for a straight 12 mm diameter probe up to 80 mm long to intercept laser radiation of Class 2, 2M or 3R, or
b) For levels of laser radiation within a housing that exceed the limits in a) the capability for any part of the human body to meet hazardous laser radiation that can be reflected directly by any single introduced flat surface from the interior of the product through any opening in its protective housing

3.37
integrated radiance
the integral of the radiance over a given exposure time expressed as radiant energy per unit area of a radiating surface per unit solid angle of emission (usually expressed in $J \cdot m^{-2} \cdot sr^{-1}$)

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

3.39
irradiance
quotient of the radiant flux $d\Phi$ incident on an element of a surface by the area dA of that element

Symbol: E $\quad E = \frac{d\Phi}{dA}$

SI unit: watt per square metre ($W \cdot m^{-2}$)

3.40
laser
any device which can be made to produce or amplify electromagnetic radiation in the wavelength range from 180 nm to 1 mm primarily by the process of controlled stimulated emission.

NOTE This definition is different from IEV 845-04-39.

3.41
laser controlled area
an area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards

3.42
laser energy source
any device intended for use in conjunction with a laser to supply energy for the excitation of electrons, ions or molecules. General energy sources such as electrical supply mains or batteries shall not be considered to constitute laser energy sources

3.43
laser hazard area
see nominal ocular hazard area (3.59)

3.44
laser fibre optic transmission system
a system consisting of one or more laser transmitters and associated fibre optic cable

3.45
laser product
any product or assembly of components which constitutes, incorporates or is intended to incorporate a laser or laser system, and which is not sold to another manufacturer for use as a component (or replacement for such component) of an electronic product

3.46
laser radiation
all electromagnetic radiation emitted by a laser product between 180 nm and 1 mm which is produced as a result of controlled stimulated emission

3.47
laser safety officer
one who is knowledgeable in the evaluation and control of laser hazards and has responsibility for oversight of the control of laser hazards

3.48
laser system
a laser in combination with an appropriate laser energy source with or without additional incorporated components

3.49
levelling laser product
see alignment laser product (3.4)

3.50
light emitting diode (LED)
any semiconductor p-n junction device which can be made to produce electromagnetic radiation by radiative recombination in the semiconductor in the wavelength range from 180 nm to 1 mm. (The optical radiation is produced primarily by the process of spontaneous emission, although some stimulated emission may be present.)

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3.51
limiting aperture
the circular area over which irradiance and radiant exposure are averaged

3.52
maintenance
the performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser product, which are to be performed by the user for the purpose of assuring the intended performance of the product. It does not include operation or service

3.53
maximum angular subtense (α_{max})
the value of angular subtense of the apparent source above which the MPEs and AELs are independent of the source size

3.54
maximum output
the maximum radiant power, and where applicable the maximum radiant energy per pulse, of the total accessible laser radiation emitted in any direction by a laser product over the full range of operational capability at any time after manufacture

3.55
maximum permissible exposure (MPE)
that level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the radiation, the pulse duration or exposure time, the tissue at risk and, for visible and near infra-red radiation in the range 400 nm to 1 400 nm, the size of the retinal image. Maximum Permissible Exposure levels are (in the existing state of knowledge) specified in clause 13. Annex A gives examples of the calculations of MPE levels

3.56
medical laser product
any laser product designed, manufactured, intended or promoted for purposes of *in vivo* diagnostic, surgical, or therapeutic laser irradiation of any part of the human body

3.57
minimum angular subtense (α_{min})
the value of angular subtense of the apparent source above which a source is considered an extended source. MPEs and AELs are independent of the source size for angular subtenses less than α_{min}

3.58
mode-locking
a regular mechanism or phenomenon, within the laser resonator, producing a train of very short pulses. While this may be a deliberate feature it may also occur spontaneously as "self-mode-locking". The resulting peak powers may be significantly greater than the mean power.

3.59
nominal ocular hazard area (NOHA)
the area within which the beam irradiance or radiant exposure exceeds the appropriate corneal maximum permissible exposure (MPE), including the possibility of accidental misdirection of the laser beam. If the NOHA includes the possibility of viewing through optical aids, this is termed the "extended NOHA"

3.60
nominal ocular hazard distance (NOHD)
the distance at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE). If the NOHD includes the possibility of optically-aided viewing, this is termed the "extended NOHD"

3.61
operation
the performance of the laser product over the full range of its intended functions. It does not include maintenance or service

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)

3.63
protective enclosure
a physical means for preventing human exposure to laser radiation unless such access is necessary for the intended functions of the installation

3.64
protective housing
those portions of a laser product (including a product incorporating an embedded laser) which are designed to prevent human access to laser radiation in excess of the prescribed AEL (generally installed by a manufacturer)

3.65
pulse duration
the time increment measured between the half peak power points at the leading and trailing edges of a pulse

3.66
pulsed laser
a laser which delivers its energy in the form of a single pulse or a train of pulses. In this part 1, the duration of a pulse is less than 0,25 s

3.67
radiance
quantity defined by the formula

$$L = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega}$$

where

$d\Phi$ is the radiant flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction;

dA is the area of a section of that beam containing the given point;

θ is the angle between the normal to that section and the direction of the beam

Symbol: L

Unit: $W \cdot m^{-2} \cdot sr^{-1}$

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

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3.68
radiant energy
time integral of the radiant flux over a given duration Δt
(IEV 845-01-27):

Symbol: Q $Q = \int_{\Delta t} \Phi dt$

SI unit: joule (J)

3.69
radiant exposure
at a point on a surface, the radiant energy incident on an element of a surface divided by the area of that element

Symbol: H $H = \frac{dQ}{dA} = \int E dt$

SI unit: joule per square metre ($J \cdot m^{-2}$)

3.70
radiant power; radiant flux
power emitted, transferred, or received in the form of radiation
(IEV 845-01-24)

Symbol: Φ, P $\Phi = \frac{dQ}{dt}$

SI unit: watt (W)

3.71
reflectance
ratio of the reflected radiant power to the incident radiant power in the given conditions
(IEV 845-04-58)

Symbol: ρ

SI unit: 1

3.72
remote interlock connector
a connector which permits the connection of external controls placed apart from other components of the laser product (see 4.4)

3.73
safety interlock
an automatic device associated with the protective housing of a laser product to prevent human access to Class 3 or Class 4 laser radiation when that portion of the housing is removed

3.74
scanning laser radiation
laser radiation having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference

3.75
service
the performance of those procedures or adjustments described in the manufacturer's service instructions, which may affect any aspect of the product's performance. It does not include maintenance or operation

3.76
service connection
an access point in a laser fibre optic transmission system which is designed for service and requires a tool to disconnect

3.77
service panel
an access panel that is designed to be removed or displaced for service

3.78
single fault condition
any single fault that might occur in a product and the direct consequences of that fault

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

3.80
specular reflection
a reflection from a surface which maintains angular correlation between incident and reflected beams of radiation, as with reflections from a mirror

3.81
surveying laser product
see alignment laser product (3.4)

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))

3.84
tool
denotes a screwdriver, a coin or other object which may be used to operate a screw or similar fixing means

3.85
transmittance
ratio of the transmitted radiant flux to the incident flux in the given conditions
(IEV 845-04-59)

Symbol: τ

SI unit: 1

3.86
transmittance (optical) density
logarithm to base ten of the reciprocal of the Transmittance τ
(IEV 845-04-66)

Symbol: D $D = -\log_{10} \tau$

3.87
visible radiation (light)
any optical radiation capable of causing a visual sensation directly
(IEV 845-01-03)

NOTE In this part 1, this is taken to mean electromagnetic radiation for which the wavelength of the monochromatic components lie between 400 nm and 700 nm.

3.88
workpiece
an object intended for processing by laser radiation

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Section Two – Manufacturing requirements

4 Engineering specifications

4.1 General remarks

Laser products require certain built-in safety features, depending on the class to which they have been assigned by the manufacturer. The requirements for these are given in 4.2 to 4.10. The manufacturer shall ensure that the personnel responsible for the classification of laser products and systems have received training to an appropriate level which allows them to understand the full implications of the classification scheme.

4.1.1 Modification

If the modification of a previously classified laser product affects any aspects of the product's performance or intended functions within the scope of this standard, the person or organization performing any such modification is responsible for ensuring the reclassification and relabelling of the laser product.

4.2 Protective housing

4.2.1 General

Each laser product shall have a protective housing which, when in place, prevents human access to laser radiation (including errant laser radiation) in excess of Class 1, except when human access is necessary for the performance of the function(s) of the product. (See annex E for guidance on this requirement for high power lasers).

4.2.2 Service

Any parts of the housing or enclosure of a laser product (including embedded laser products) that can be removed or displaced for service and which would allow access to laser radiation in excess of the AEL assigned and are not interlocked (see 4.3) shall be secured in such a way that removal or displacement of the parts requires the use of tools.

4.2.3 Removable laser system

If an embedded laser product or a laser system can be removed from its protective housing or enclosure and operated without modification, the laser shall comply with the manufacturing requirements of clauses 4 and 5 that are appropriate to its class, except for laser products which are sold to other manufacturers for use as components of any system for subsequent sale which are not subject to this standard, since the final product will itself be subject to this standard.

4.3 Access panels and safety interlocks

4.3.1 A safety interlock shall be provided for access panels of protective housings when both of the following conditions are met:

a) the access panel is intended to be removed or displaced during maintenance or operation, and
b) the removal of the panel gives access to laser radiation levels designated by "X" in the table below.

The table below indicates (X) the necessity of a safety interlock.

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.

The safety interlock shall be of a design which prevents the removal of the panel until the accessible emission levels are below the AEL of the Class assigned and, in any case, below the limits specified in 4.3.1b). Inadvertent resetting of the interlock shall not in itself restore emission values above the AEL of the Class assigned nor above the limits specified in 4.3.1b).

4.3.2 If a deliberate override mechanism is provided, the manufacturer shall also provide adequate instructions about safe methods of working. It shall not be possible to leave the override in operation when the access panel is returned to its normal position. The interlock shall be clearly associated with a label conforming to 5.9.2. Use of the override shall give rise to a distinct visible or audible warning whenever the laser is energized or capacitor banks are not fully discharged, whether or not the access panel is removed or displaced. Visible warnings shall be clearly visible through protective eyewear specifically designed or specified for the wavelength(s) of the accessible laser radiation.

4.4 Remote interlock connector

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

Each Class 3B and Class 4 laser system shall incorporate a key-operated master control. The key shall be removable and the laser radiation shall not be accessible when the key is removed. In this part 1 the term "key" includes any other control devices, such as magnetic cards, cipher combinations, etc.

4.6 Laser radiation emission warning

4.6.1 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. The warning device shall be fail-safe or redundant. Any visible warning device shall be clearly visible through protective eyewear specifically designed for the wavelength(s) of the emitted laser radiation. The visible warning device(s) shall be located so that viewing does not require exposure to laser radiation in excess of the AEL for Class 1M and 2M.

4.6.2 Each operational control and laser aperture that can be separated by 2 metres or more from a radiation warning device shall itself be provided with a radiation warning device. The warning device shall be clearly visible or audible to the person in the vicinity of the operational control or laser aperture.

4.6.3 Where the laser emission may be distributed through more than one output aperture, then a visible warning device shall clearly indicate the output aperture or apertures through which laser emission can occur, in accordance with 4.6.1.

4.7 Beam stop or attenuator

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.

4.8 Controls

Each laser product shall have controls located so that adjustment and operation do not require exposure to laser radiation of Class 3R, 3B or Class 4.

4.9 Viewing optics

Any viewing optics, viewport or display screen incorporated in a laser product shall provide sufficient attenuation to prevent human access to laser radiation in excess of the AEL for Class 1M, and for any shutter or variable attenuator incorporated in the viewing optics, viewport or display screen, a means shall be provided to:

a) prevent human access to laser radiation in excess of the AEL for Class 1M when the shutter is opened or the attenuation varied;

b) prevent opening of the shutter or variation of the attenuator when exposure to laser radiation in excess of the AEL for Class 1M is possible.

4.10 Scanning safeguard

Laser products intended to emit scanned radiation, and classified on this basis, shall not, as a result of scan failure or of variation in either scan velocity or amplitude, permit human access to laser radiation in excess of the AEL for the assigned class.

4.11 Alignment aids

Where routine maintenance requires the alignment of beam path components, then a safe means of achieving this shall be provided.

4.12 "Walk-in" access

If a protective housing is equipped with an access panel which provides "walk-in" access then:

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.

4.13 Environmental conditions

The laser product shall meet the safety requirements defined in this standard under all expected operating conditions appropriate to the intended use of the product. Factors to be considered shall include:

– climatic conditions (e.g. temperature, relative humidity);

– vibration and shock.

If no provisions are made in the product safety standard, the relevant subclauses of IEC 61010-1 shall apply.

NOTE Requirements related to electromagnetic susceptibility are under consideration.

4.14 Protection against other hazards

4.14.1 Non-optical hazards

The requirements of the relevant product safety standard shall be fulfilled during operation and in the event of a single fault for the following:

– electrical hazards;
– excessive temperature;
– spread of fire from the equipment;
– sound and ultrasonics;
– harmful substances;
– explosion.

If no provisions are included in the product safety standard, the relevant subclauses of IEC 61010-1 shall apply.

NOTE Many countries have regulations for the control of harmful substances. Contact the appropriate national agency for these requirements.

4.14.2 Collateral radiation

The protective housing of laser products will normally protect against the hazards of collateral radiation (e.g. UV, visible, IR). However, if a concern exists that accessible collateral radiation might be hazardous, the laser MPE values may be applied to conservatively evaluate this risk.

5 Labelling

5.1 General

Each laser product shall carry label(s) in accordance with the requirements of the following clauses. The labels shall be permanently fixed, legible, and clearly visible during operation, maintenance or service, according to their purpose. They shall be so positioned that they can be read without the necessity for human exposure to laser radiation in excess of the AEL for Class 1. Text borders and symbols shall be black on a yellow background except for Class 1 where this colour combination need not be used.

If the size or design of the product makes labelling impractical, the label should be included with the user information or on the package.

5.2 Class 1 and Class 1M

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.

5.3 Class 2 and Class 2M

Each Class 2 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 BEAM
CLASS 2 LASER PRODUCT

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 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

5.5 Class 3B

Each Class 3B 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 3B LASER PRODUCT

5.6 Class 4

Each Class 4 laser product shall have affixed a warning label (Figure 14) and an explanatory label (figure 15) bearing the words:

LASER RADIATION
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION
CLASS 4 LASER PRODUCT

5.7 Aperture label

Each Class 3R, Class 3B and Class 4 laser product shall have affixed a label close to each aperture through which laser radiation in excess of the AEL for Class 1 or Class 2 is emitted. The label(s) shall bear the words:

LASER APERTURE
or
AVOID EXPOSURE – LASER RADIATION IS
EMITTED FROM THIS APERTURE

5.8 Radiation output and standards information

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 Labels for access panels

5.9.1 Labels for panels

Each connection, each panel of a protective housing, and each access panel of a protective enclosure which when removed or displaced permits human access to laser radiation in excess of the AEL for Class 1 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):

CAUTION – LASER RADIATION WHEN OPEN

In addition, this label shall bear the words:

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

Appropriate labels shall be clearly associated with each safety interlock which may be readily overridden and which would then permit human access to laser radiation in excess of the AEL of Class 1. 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

5.10 Warning for invisible laser radiation

In many cases, the wording prescribed for labels in clause 5 includes the phrase "laser radiation". If the output of the laser is outside the wavelength range from 400 nm to 700 nm, this shall be modified to read "Invisible laser radiation", or if the output is at wavelengths both inside and outside this wavelength range, to read "Visible and invisible laser radiation".

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

The wording "laser radiation" for labels in clause 5 may be modified to read "laser light" if the output of the laser is in the (visible) wavelength range from 400 nm to 700 nm.

5.12 Warning for LED radiation

For LED radiation the word "Laser" on the labels in clause 5 shall be replaced by "LED".

6 Other informational requirements

6.1 Information for the user

Manufacturers of laser products shall provide (or see to the provision of) as an integral part of any user instruction or operation manual which is regularly supplied with the laser product:

a) Adequate instructions for proper assembly, maintenance, and safe use, including clear warnings concerning precautions to avoid possible exposure to hazardous laser radiation.

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.

c) A statement in appropriate units of beam divergence for collimated beams, pulse duration and maximum output, with the magnitudes of the cumulative measurement uncertainty and any expected increase in the measured quantities at any time after manufacture added to the values measured at the time of manufacture (duration of pulses resulting from unintentional mode-locking need not be specified; however, those conditions associated with the product known to result in unintentional mode-locking shall be specified).

   Additionally, for embedded laser products and other incorporated laser products, similar information shall be provided to describe the incorporated laser. The information shall also include appropriate safety instructions to the user to avoid inadvertent exposure to hazardous laser radiation.

d) Legible reproductions (colour optional) of all required labels and hazard warnings to be affixed to the laser product or provided with the laser product. The corresponding position of each label affixed to the product shall be indicated or, if provided with the product, a statement that such labels could not be affixed to the product but were supplied with the product and a statement of the form and manner in which they were supplied shall be provided.

e) A clear indication in the manual of all locations of laser apertures.

f) A listing of controls, adjustments and procedures for operation and maintenance, including the warning "Caution – Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure".

g) In the case of laser products that do not incorporate the laser energy source necessary for laser emission, a statement of the compatibility requirements for a laser energy source to ensure safety.

6.2 Purchasing and servicing information

Manufacturers of laser products shall provide or cause to be provided:

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.

b) To servicing dealers and distributors, and to others upon request, adequate instructions for service adjustments and service procedures for each laser product model, which includes clear warnings and precautions to be taken to avoid possible exposure to radiation and other hazards and a schedule of maintenance necessary to keep the product in compliance; and, in all such service instructions, a listing of those controls and procedures which could be utilized by persons other than the manufacturer or his agents to increase accessible emission levels of radiation, and a clear description of the location of displaceable portions of the protective housing which could allow access to laser radiation in excess of the accessible limits in tables 1, 2, 3 and 4. The instructions shall include protective procedures for service personnel, and legible reproductions (colour optional) of required labels and hazard warnings.

7 Additional requirements for specific laser products

7.1 Medical laser products

Each medical laser product shall comply with all of the applicable requirements for laser products of its class. In addition, any Class 3B or Class 4 medical laser product shall comply with IEC 60601-2-22.

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.

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 α < 1,5 mrad but $7 \times \alpha$ > 1,5 mrad, the limits for α > 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.

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:

$$d = (7\ \text{mm})\sqrt{\frac{\alpha_{max}}{\alpha + 0{,}46\ \text{mrad}}}$$ If $\alpha < \alpha_{min}$, d = 50 mm. If $\alpha \geq \alpha_{max}$, d = 7 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
≥ 1 400 nm to 4 000 nm	25	2 000	7	14	1 for $t \le 0{,}35$ s 1,5 $t^{3/8}$ for $0{,}35\ s < t < 10$ 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 $0{,}35\ s < t < 10$ 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

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

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

$$r = (100\ \text{mm})\sqrt{\frac{+\ 0{,}46\ \text{mrad}}{\text{max}}}$$ 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.

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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)).

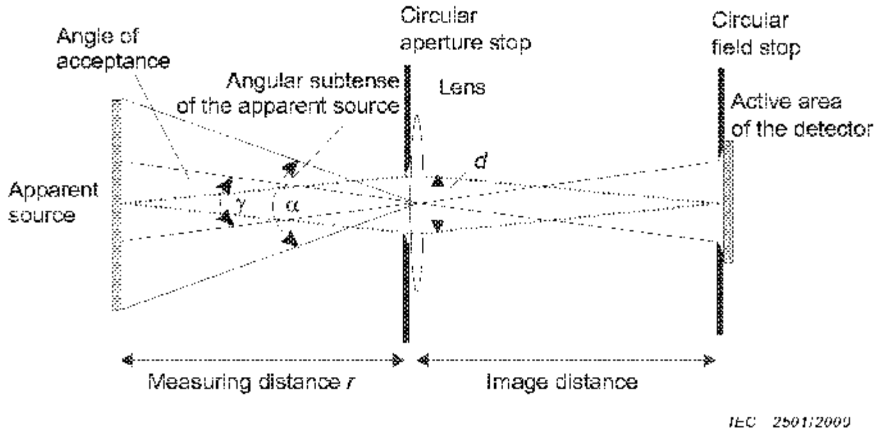

Figure 16a

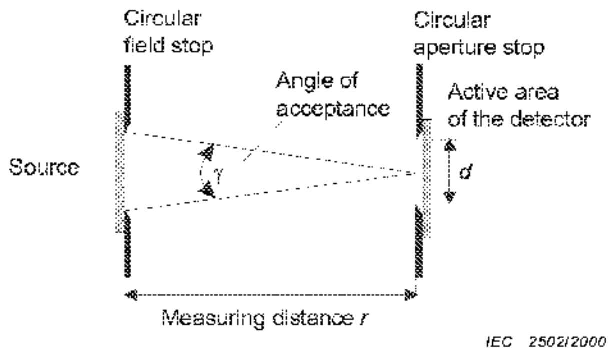

Figure 16b

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.

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

Wavelength 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 / $7,9 \times 10^{-7}$ C_2 J ($t > T_1$)						$7,9 \times 10^{-7}$ 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[c]	$5,8 \times 10^{-9}$ C_6 J	$1,0\ t^{0,75}$ C_6 J	2×10^{-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 γ_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: ($t < T_2$) $7 \times 10^{-4}\ t^{0,75}$ C_6 J / ($t > T_2$) $\alpha < 1,5$ mrad: $3,9 \times 10^{-4}$ W; $\alpha > 1,5$ mrad: 7×10^{-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	2×10^{-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 / ($t > T_2$) $\alpha \le 1,5$ mrad: $3,9 \times 10^{-4}$ C_4 C_7 W; $\alpha > 1,5$ mrad: 7×10^{-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	2×10^{-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 × 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.

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

Wavelength λ nm	Emission duration *t* s	Class 2 AEL
400 to 700	$t < 0{,}25$	Same as Class 1 AEL
	$t \geq 0{,}25$	$C_6 \times 10^{-3}$ W *
* For correction factor and units see "Notes to tables 1 to 4".		

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

Wavelength 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 10^3	10^3 to 3×10^4
180 to 302,5	Not appropriate		Not appropriate							
302,5 to 315	$1,2 \times 10^5$ W		($t \le T_1$) $4 \times 10^{-6}\ C_1$ J / $4,0 \times 10^{-6}\ C_2$ J ($t > T_1$)						$4,0 \times 10^{-6}\ C_2$ J	
315 to 400			$4,0 \times 10^{-6}\ C_1$ J						$4,0 \times 10^{-2}$ J	$4,0 \times 10^{-5}$ W
400 to 700	$2,9 \times 10^{-8}\ C_6$ J	$5,0\ t^{0,75}\ C_6$ J	$1 \times 10^{-6}\ C_6$ J		($t < 0,25$ 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)			$5,0 \times 10^{-3}\ C_6$ W	$5,0 \times 10^{-3}\ C_6$ W	
700 to 1 050	$2,9 \times 10^{-8}\ C_4\ C_6$ J	$5,0\ t^{0,75}\ C_4\ C_6$ J	$1 \times 10^{-6}\ C_4\ C_6$ J		$3,5 \times 10^{-3}\ t^{0,75}\ C_4\ C_6$ J				$\alpha \le 1,5$ 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	
1 050 to 1 400	$2,9 \times 10^{-7}\ C_6\ C_7$ J	$52\ t^{0,75}\ C_6\ C_7$ J	$1 \times 10^{-5}\ C_6\ C_7$ J			$1,8 \times 10^{-2}\ t^{0,75}\ C_6\ C_7$ J				
1 400 to 1 500	4×10^6 W		4×10^{-3} J				$2,2 \times 10^{-2}\ t^{0,25}$ J	$5 \times 10^{-2}\ t$ J	$5,0 \times 10^{-2}$ W	
1 500 to 1 800	4×10^7 W		4×10^{-2} J					$9 \times 10^{-2}\ t^{0,75}$ J		
1 800 to 2 600	4×10^6 W		4×10^{-3} J				$2,2 \times 10^{-2}\ t^{0,25}$ J	$5 \times 10^{-2}\ t$ J		
2 600 to 4 000	4×10^5 W		4×10^{-4} J	$2,2 \times 10^{-2}\ t^{0,25}$ J						
4 000 to 10^6	5×10^{11} W·m^{-2}		500 J·m^{-2}	$2,8 \times 10^4\ t^{0,25}$ J·m^{-2}					5 000 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.

Table 4 – Accessible emission limits for Class 3B laser products

Wavelength λ nm \ Emission duration t s	<10^{-9}	10^{-9} to 0,25	0,25 to 3×10^4
180 to 302,5	$3,8 \times 10^5$ W	$3,8 \times 10^{-4}$ J	$1,5 \times 10^{-3}$ W
302,5 to 315	$1,25 \times 10^4$ C_2 W	$1,25 \times 10^{-5}$ C_2 J	5×10^{-5} C_2 W
315 to 400	$1,25 \times 10^8$ W	0,125 J	0,5 W
400 to 700	3×10^7 W	0,03 J for $t < 0,06$ s 0,5 W for $t \geq 0,06$ s	0,5 W
700 to 1 050	3×10^7 C_4 W	0,03 C_4 J for $t < 0,06$ C_4 s 0,5 W for $t \geq 0,06$ C_4 s	0,5 W
1 050 to 1 400	$1,5 \times 10^8$ W	0,15 J	0,5 W
1 400 to 10^6	$1,25 \times 10^8$ W	0,125 J	0,5 W
For correction factors and units, see "Notes to tables 1 to 4".			

Notes to tables 1 to 4

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 arc illustrated in figurcs 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 $\alpha \leq \alpha_{min}$	400 to 1 400	[c]
$C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$	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 $\alpha < 1,5$ mrad and $T_2 = 100$ s for $\alpha > 100$ 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 shall be equal to α_{max}

$\alpha_{min} = 1,5$ mrad

$\alpha_{max} = 100$ 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.

Section Three – User's guide

NOTE Because of the nature of these guidelines, this section makes recommendations with the verb "should" for safety precautions and control measures to be taken by the user of a laser product without distinguishing between the relative hazard presented by Class 3B or Class 4 lasers. It is left to the user to specify whether "should" or "shall " is to be used in the implementation of these control measures.

10 Safety precautions

10.1 General

This section specifies safety precautions and control measures to be taken by the user of a laser product, in accordance with its hazard classification. Often users can use the manufacturer's classification of the product for classification of the laser installation, thus avoiding all measurements. This section is supplied for the user's information. 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. Wherever practicable, laser protective enclosures should be used for lasers of Class 3B or Class 4. Warning labels should be placed upon removable parts of protective enclosures or at service connections where a hazard is introduced by their removal or by disconnection.

The purpose of safety precautions and control measures is to reduce the possibility of exposure to hazardous levels of laser radiation, and to other associated hazards. Therefore, it may not be necessary to implement all of the control measures given. Whenever the application of any one or more control measures reduces the possible exposure to a level at or below the applicable MPE, then the application of additional control measures should not be necessary.

If a user modification of a previously classified laser product affects any aspect of the product's performance or intended functions within the scope of this standard, the person or organization performing any such modification is responsible for ensuring the reclassification and relabelling of the laser product.

10.2 Use of remote interlock connector

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).

The person in charge may be permitted momentary override of the remote interlock connector to allow access to other authorized persons if it is clearly evident that there is no optical radiation hazard at the time and point of entry.

10.3 Key control

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

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).

10.5 Warning signs

The entrances to areas or protective enclosures containing Class 3B and Class 4 laser products should be posted with appropriate warning signs.

10.6 Beam paths

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

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).

10.8 Eye protection

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.

The following should be considered when specifying suitable protective eyewear:

a) wavelength(s) of operation;
b) radiant exposure or irradiance;
c) maximum permissible exposure (MPE);
d) optical density of eyewear at laser output wavelength;
e) visible light transmission requirements;
f) radiant exposure or irradiance at which damage to eyewear occurs;
g) need for prescription glasses;
h) comfort and ventilation;
i) degradation or modification of absorbing media, even if temporary or transient;
j) strength of materials (resistance to shock);
k) peripheral vision requirements;
l) any relevant national regulations.

10.8.1 Identification of eyewear

All laser protective eyewear shall be clearly labelled with information adequate to ensure the proper choice of eyewear with particular lasers.

10.8.2 Required optical density

The spectral optical density D_λ of laser protective eyewear is normally highly wavelength dependent. Where protective eyewear is required to cover a band of radiation, the minimum value of D_λ measured within the band shall be quoted. The value of D_λ required to give eye protection can be calculated from the formula:

$$D_\lambda = \log_{10} \frac{H_0}{\text{MPE}}$$

where H_0 is the expected unprotected eye exposure level.

10.8.3 Protective eyewear

Protective eyewear should be comfortable to wear, provide as wide a field of view as possible, maintain a close fit while still providing adequate ventilation to avoid problems in misting up and provide adequate visual transmittance. Care should be taken to avoid, as far as is possible, the use of flat reflecting surfaces which might cause hazardous specular reflections. It is important that the frame and any side-pieces should give equivalent protection to that afforded by the lens(es).

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

Where personnel may be exposed to levels of radiation that exceed the MPE for the skin, suitable clothing should be provided. Class 4 lasers especially are a potential fire hazard and protective clothing worn should be made from a suitable flame and heat resisting material.

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

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.

Because of this hazard potential, only persons who have received training to an appropriate level should be placed in control of such systems. The training, which may be given by the manufacturer or supplier of the system, the laser safety officer, or by an approved external organization, should include, but is not limited to:

a) familiarization with system operating procedures;
b) the proper use of hazard control procedures, warning signs, etc.;
c) the need for personal protection;
d) accident reporting procedures;
e) bioeffects of the laser upon the eye and the skin.

See also clause 12.

10.11 Medical supervision

In the absence of national regulations, the following recommendations should be taken into consideration:

a) the value of medical surveillance of laser workers is a fundamental problem as yet unresolved by the medical profession. If ophthalmic examinations are undertaken, they should be carried out by a qualified specialist and should be confined to workers using Class 3B and Class 4 lasers;
b) a medical examination by a qualified specialist should be carried out immediately after an apparent or suspected injurious ocular exposure. Such an examination should be supplemented with a full biophysical investigation of the circumstances under which the accident occurred;
c) pre, interim, and post employment ophthalmic examinations of workers using Class 3B and Class 4 lasers have value for medical legal reasons only and are not a necessary part of a safety programme.

11 Hazards incidental to laser operation

Depending on the type of laser used, associated hazards involved in laser operations may include the following:

11.1 Atmospheric contamination

a) Vapourized target material and reaction products from laser cutting, drilling, and welding operations. These materials may well include asbestos, carbon monoxide, carbon dioxide, ozone, lead, mercury, other metals, and biological material.
b) Gases from the flowing gas laser systems or from the by-products of laser reactions, such as bromine, chlorine, and hydrogen cyanide.
c) Gases or vapours from cryogenic coolants.
d) Gases used to assist laser-target interactions, such as oxygen.

11.2 Collateral radiation hazards

11.2.1 Ultra-violet collateral radiation

There may be a considerable hazard from the ultra-violet radiation associated with flashlamps and CW laser discharge tubes, especially when ultra-violet transmitting tubing or mirrors (such as quartz) are used.

11.2.2 Visible and infra-red collateral radiation

The visible and near infra-red radiation emitted from flash tubes and pump sources and target re-radiation may be of sufficient radiance to produce potential hazard.

11.3 Electrical hazards

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

Unless properly shielded, circuit components such as electronic tubes working at anode voltages greater than 5 kV may emit X-rays.

11.4 Cryogenic coolants

Cryogenic liquids may cause burns and require special handling precautions.

11.5 Materials processing

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.

11.6 Other hazards

The potential for explosions at the capacitor bank or optical pump systems exists during the operation of some high-power laser systems. There is a possibility of flying particles from the target area in the laser cutting, drilling, and welding operations. Explosive reactions of chemical laser reagents or other gases used within the laboratory are also possible.

12 Procedures for hazard control

12.1 General

Three aspects of the use of lasers need to be taken into account in the evaluation of the possible hazards and in the application of control measures:

a) the capability of the laser or laser system to injure personnel. This includes any consideration of human access to the main exit port or any subsidiary port;

b) the environment in which the laser is used;

c) the level of training of the personnel who operate the laser or who may be exposed to its radiation.

The practical means for evaluation and control of laser radiation hazards is to classify laser systems according to their relative hazard potential, and then to specify appropriate controls for each class. The use of the classification system will in most cases preclude any requirement for radiometric measurements by the user.

The classification scheme relates specifically to the accessible emission from the laser system and the potential hazard based on its physical characteristics. However, environmental and personnel factors are also relevant in determining the control measures required, and a responsible person should be designated as laser safety officer, to be responsible for providing informed judgments on situations not specifically covered by this standard.

The following details relate to safe operation of laser products in:

- outdoor and construction environments where administrative controls often provide the only reasonable approach to safe operation;
- laboratory and workshop environments where engineering controls may play the greatest role;
- display and demonstration environments, where pre-planning, delineation and control of access often provide the only reasonably practicable approach to safe operation.

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.

12.3 Personal protection

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.

When personnel may be exposed to potentially hazardous laser radiation (Class 3B and Class 4) adequate personal protection should be provided.

12.4 Laser demonstrations, displays and exhibitions

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.

12.5 Laboratory and workshop laser installations

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.

12.5.2 Class 3B laser products

Class 3B lasers are potentially hazardous if a direct beam or specular reflection is viewed by the unprotected eye (intrabeam viewing). The following precautions should be taken to avoid direct beam viewing and to control specular reflections.

a) The laser should only be operated in a controlled area.

b) Care should be exercised to prevent unintentional specular reflections.

c) The laser beam should be terminated where possible at the end of its useful path by a material that is diffuse and of such a colour and reflectivity as to make beam positioning possible while still minimizing the reflection hazards.

   NOTE Conditions for safe viewing of diffuse reflections for Class 3B visible lasers are: minimum viewing distance of 13 cm between screen and cornea and a maximum viewing time of 10 s. Other viewing conditions require a comparison of the diffuse reflection exposure with the MPE.

d) Eye protection is required if there is any possibility of viewing either the direct or specularly reflected beam, or of viewing a diffuse reflection not complying with the conditions of item c).

e) The entrances to areas should be posted with a standard laser warning sign.

12.5.3 Class 4 laser products

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.

a) Beam paths should be enclosed whenever practicable. Access to the laser environment during laser operation should be limited to persons wearing proper laser protective eyewear and protective clothing.

   Beam paths should avoid work area, where possible, and long sections of tubes should be mounted so that thermal expansion, vibration, and other sources of movements in them do not significantly affect the alignment of beam forming components.

b) Class 4 lasers should be operated by remote control whenever practicable, thus eliminating the need for personnel to be physically present in the laser environment.

c) Good room illumination is important in areas where laser eye protection is worn. Light-coloured diffuse wall surfaces help to achieve this condition.

d) Fire, thermally induced aberrations in optical components, and the melting or vaporization of solid targets designed to contain the laser beam, are all potential hazards induced by the radiation from Class 4 lasers. A suitable beam stop should be provided, preferably in the form of an adequately cooled metal or graphite target. Very high power densities can be handled by absorbing the radiation over several reflections, each reflecting surface being inclined at such an angle to the incident radiation as to spread the laser power over a wide area.

e) Special precautions may be required to prevent unwanted reflections in the invisible spectrum from far infra-red laser radiation, and the beam and target area should be surrounded by a material opaque at the laser wavelength. (Even dull metal surfaces may be highly specular at the CO_2 wavelength of 10,6 μm.)

   Local screening should be used wherever practicable to reduce the extent of reflected radiation.

f) The alignment of optical components in the path of a Class 4 laser beam should be initially and periodically checked.

12.6 Outdoor and construction laser installations

12.6.1 Class 2 laser products

Wherever reasonably practicable the beam should be terminated at the end of its useful path, and the laser should not be aimed at personnel (at head height).

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.

c) Wherever practicable, mechanical or electronic means should be used to assist in the alignment of the laser.

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.

e) The laser beam should be terminated at the end of its useful beam path and should in all cases be terminated if the hazardous beam path (to NOHD) extends beyond the controlled area.

f) The laser beam path should be located well above or below eye level wherever practicable.

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).

h) When not in use the laser should be stored in a location where unauthorized personnel cannot gain access.

12.6.3 Class 3B and Class 4 laser products

Class 3B and Class 4 lasers in outdoor and similar environments should only be operated by personnel adequately trained in their use and approved by the laser safety officer. To minimize possible hazards, the following precautions should be employed in addition to those given in 12.6.2.

a) Personnel should be excluded from the beam path at all points where the beam irradiance or radiant exposures exceed the MPEs unless they are wearing appropriate protective eyewear and clothing. Engineering controls such as physical barriers, interlocks limiting the beam traverse and elevation, etc. should be used wherever practicable to augment administrative controls.

   An alternative solution is to place the operator inside a local enclosure which provides protection from errant beams and gives good all around visibility.

b) The intentional tracking on non-target vehicular traffic or aircraft should be prohibited within the nominal ocular hazard distance.

c) The beam paths should, whenever practicable, be cleared of all surfaces capable of producing unintended reflections that are potentially hazardous, or the hazard area should be extended appropriately.

d) Although direct intrabeam viewing of Class 3B lasers is usually hazardous, a beam may in all cases be safely viewed via a diffuse reflector under the following conditions:

– minimum viewing distance between screen and cornea of 13 cm;

– maximum viewing time of 10 s.

If either one of these conditions is not satisfied, a careful evaluation of the hazard is necessary.

12.6.4 Lasers for surveying, alignment, and levelling

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.

13 Maximum permissible exposures

13.1 General remarks

Maximum permissible exposure values are for users and are set below known hazard levels, and are based on the best available information from experimental studies. The MPE values should be used as guides in the control of exposures, and should not be regarded as precisely defined dividing lines between safe and dangerous levels. In any case, exposure to laser radiation shall be as low as possible. When a laser emits radiation at several widely different wavelengths, or where pulses are superimposed upon a CW background, calculations of the hazard may be complex.

Exposures from several wavelengths should be assumed to have an additive effect on a proportional basis of spectral effectiveness according to the MPEs of tables 6 and 8 provided that:

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

b) the spectral regions are shown as additive by the symbols (o) for ocular and (s) for skin exposure in the matrix of table 5.

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

Spectral region*	UV-C and UV-B 180 nm to 315 nm	UV-A 315 nm to 400 nm	Visible and IR-A 400 nm to 1 400 nm	IR-B and IR-C 1 400 nm to 10^6 nm
UV-C and UV-B 180 nm to 315 nm	o s			
UV-A 315 nm to 400 nm		o s	s	o s
Visible and IR-A 400 nm to 1 400 nm		s	o** s	s
IR-B and IR-C 1 400 nm to 10^6 nm		o s	s	o s

* For definitions of spectral regions, see table B1.

** 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.

Where the wavelengths radiated are not shown as additive, the hazards should be assessed separately. For wavelengths which are shown as additive, but when the pulse widths or exposure times are not within one order of magnitude, extreme caution is required (e.g., in the case of simultaneous exposure to pulsed and CW radiation).

13.2 Limiting apertures

An appropriate aperture should be used for all measurements and calculations of exposure values. This is the limiting aperture and is defined in terms of the diameter of a circular area over which the irradiance or radiant exposure is to be averaged. Values for the limiting apertures are shown in table 7.

For repetitively pulsed laser exposures within the spectral range between 1 400 nm and 10^5 nm, the 1 mm aperture is used for evaluating the hazard from an individual pulse; whereas the 3,5 mm aperture is applied for evaluating the MPE applicable for exposures greater than 3 s.

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.

13.3 Repetitively pulsed or modulated lasers

Since there are only limited data on multiple pulse exposure criteria, caution must be used in the evaluation of exposure to repetitively pulsed radiation. The following methods should be used to determine the MPE to be applied to repetitive exposures to repetitively pulsed radiation.

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).

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

b) The average exposure for a pulse train of exposure duration T shall not exceed the MPE given in tables 6 and 8 for a single pulse of exposure duration T.

c) 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.

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:

$$MPE_{train} = MPE_{single} \times C_5^{*}$$

where

MPE_{train} = MPE for any single pulse in the pulse train

MPE_{single} = MPE for a single pulse

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

N = number of pulses expected in an exposure.

In some cases this value may fall below the MPE that would apply for continuous exposure at the same peak power using the same exposure time. Under these circumstances the MPE for continuous exposure may be used.

———————

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

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, 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.

13.4 Measurement conditions

In order to evaluate the actual exposure, the following measurement conditions shall be applied.

13.4.1 Limiting aperture

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

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 $10 \text{ s} < t \leq 100 \text{ s}$:	$\gamma_p = 11$ mrad
for $100 \text{ s} < t < 10^4 \text{ s}$:	$\gamma_p = 1{,}1\, t^{0{,}5}$ mrad
for $10^4 \text{ s} < t \leq 3 \times 10^4 \text{ s}$:	$\gamma_p = 110$ 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 $\alpha_{min} < \gamma < \alpha_{max}$ (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

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. Examples are provided in annex A.

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.

The correction factor C_6 is given by:

$C_6 = 1$ for $\alpha \leq \alpha_{min}$

$C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$

$C_6 = \alpha_{max}/\alpha_{min}$ for $\alpha > \alpha_{max}$

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">($t \leq T_1$) C_1 J·m^{-2}
($t > T_1$) C_2 J·m^{-2}</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">($t \leq T_2$) $18\ t^{0,75}$ C_6 J·m^{-2}
($t > T_2$) $\alpha \leq 1,5$ mrad: 10 W·m^{-2}
$\alpha > 1,5$ mrad: 18 C_6 $T_2^{-0,25}$ W·m^{-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">($t \leq T_2$) $18\ t^{0,75}$ C_4 C_6 C_7 J·m^{-2}
($t > T_2$) $\alpha \leq 1,5$ 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}</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.

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

Spectral region nm	Aperture diameter for Eye mm	Aperture diameter for 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 $0,35\ s < t < 10$ s 3,5 for $t \geq 10$ s	3,5
≥ 10^5 to 10^6	11	11

Table 8 – Maximum permissible exposure (MPE) of skin to laser radiation [1) 2)]

Wavelength λ nm \ Exposure time t s	$<10^{-9}$	10^{-9} to 10^{-7}	10^{-7} to 10^{-3}	10^{-3} to 10	10 to 10^3	10^3 to 3×10^4
180 to 302,5		30 $J \cdot m^{-2}$				
302,5 to 315	3×10^{10} $W \cdot m^{-2}$	C_1 $J \cdot m^{-2}$ ($t > T_1$) / C_2 $J \cdot m^{-2}$ ($t > T_1$)			C_2 $J \cdot m^{-2}$	
315 to 400		C_1 $J \cdot m^{-2}$			10^4 $J \cdot m^{-2}$	10 $W \cdot m^{-2}$
400 to 700	2×10^{11} $W \cdot m^{-2}$	200 $J \cdot m^{-2}$		$1,1\times10^4\ t^{0,25}$ $J \cdot m^{-2}$	2 000 $W \cdot m^{-2}$	
700 to 1 400	2×10^{11} C_4 $W \cdot m^{-2}$	200 C_4 $J \cdot m^{-2}$		$1,1\times10^4\ C_4\ t^{0,25}$ $J \cdot m^{-2}$	2 000 C_4 $W \cdot m^{-2}$	
1 400 to 1 500	10^{12} $W \cdot m^{-2}$	10^3 $J \cdot m^{-2}$		5 600 $t^{0,25}$ $J \cdot m^{-2}$	1 000 $W \cdot m^{-2}$ [3)]	
1 500 to 1 800	10^{13} $W \cdot m^{-2}$	10^4 $J \cdot m^{-2}$				
1 800 to 2 600	10^{12} $W \cdot m^{-2}$	10^3 $J \cdot m^{-2}$		5 600 $t^{0,25}$ $J \cdot m^{-2}$		
2 600 to 10^6	10^{11} $W \cdot m^{-2}$	100 $J \cdot m^{-2}$		5 600 $t^{0,25}$ $J \cdot m^{-2}$		

1) For correction factors and units see "Notes to tables 1 to 4".

2) There is only limited evidence about effects for exposures of less than 10^{-9} s. The MPEs for these exposure times have been derived by maintaining the irradiance applying at 10^{-9} s.

3) For exposed skin areas greater than 0,1 m^2, the MPE is reduced to 100 $W \cdot m^{-2}$. Between 0,01 m^2 and 0,1 m^2, the MPE varies inversely proportional to the irradiated skin area.

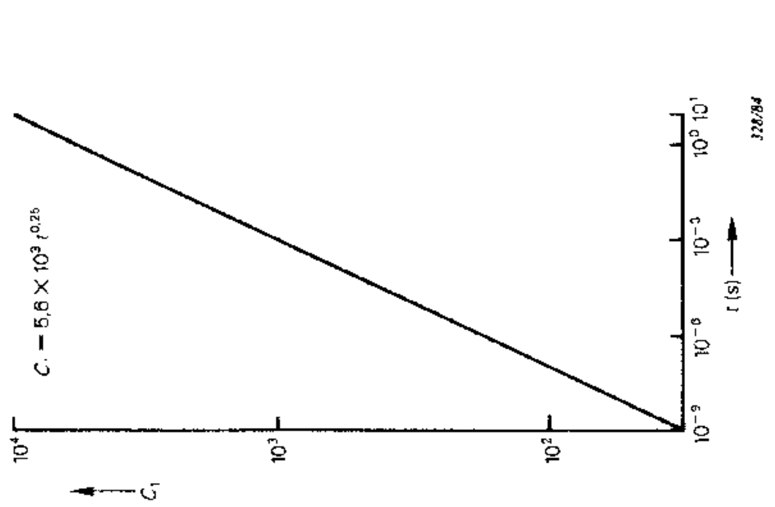

Figure 1 – Correction factor C_1 for emission durations from 10^{-9} s to 10 s

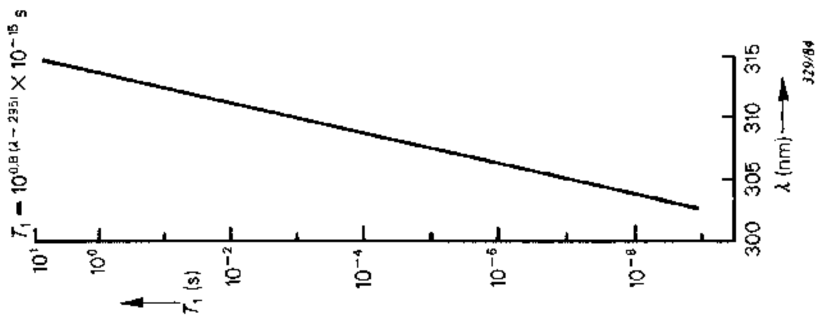

Figure 2 – Breakpoint T_1 for λ = 302,5 nm to 315 nm

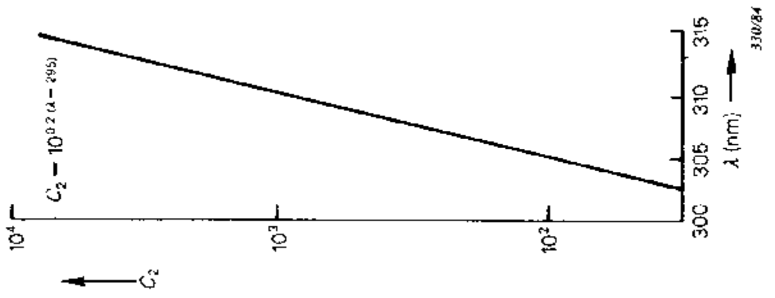

Figure 3 – Correction factor C_2 for λ = 302,5 nm to 315 nm

$T_2 = 10$	$0 < \alpha < 1,5$
$T_2 = 10 \times 10^{[(\alpha - 1,5 \text{ mrad})/98,5]}$	$1,5 < \alpha < 100$
$T_2 = 100$	$\alpha > 100$

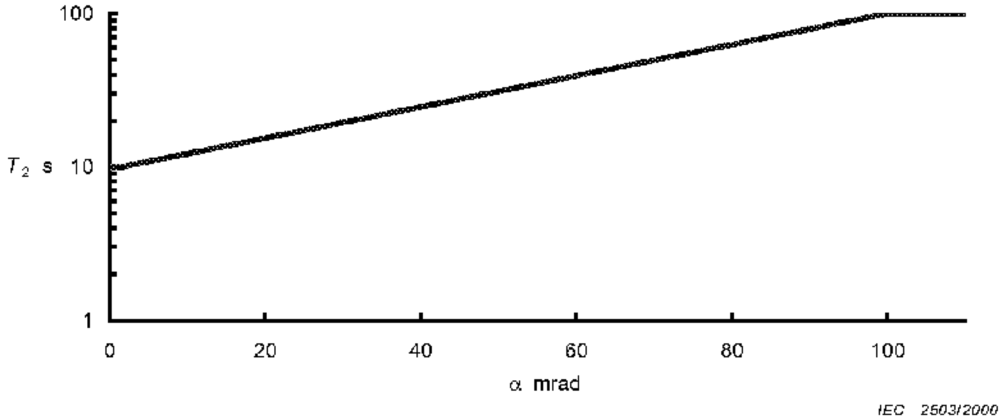

Figure 4 – Breakpoint T_2 for source size α ranging from 0 mrad to more than 100 mrad

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

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

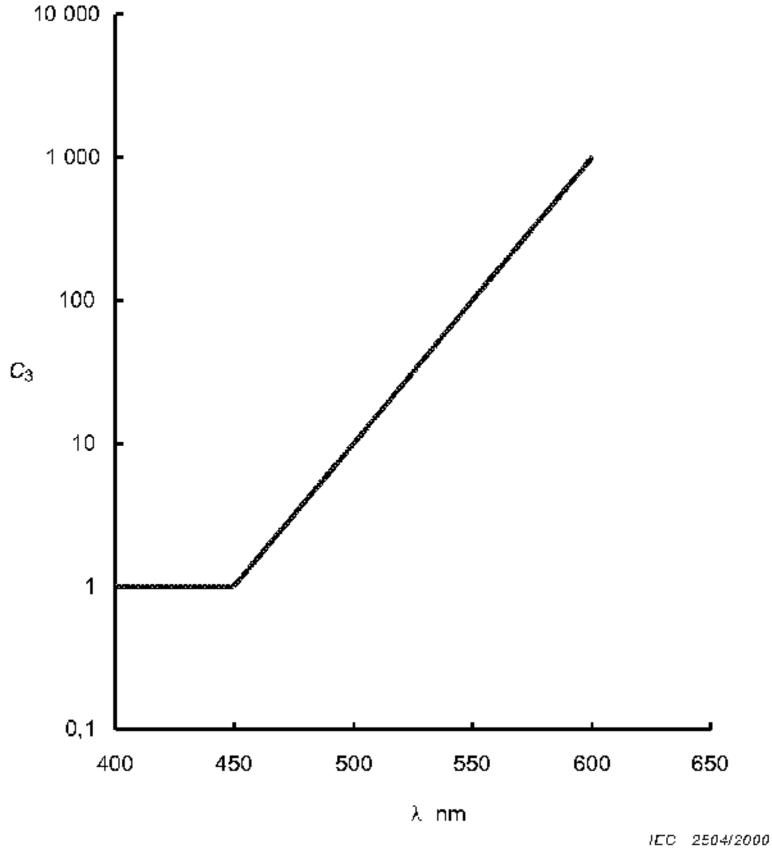

Figure 5 – Correction factor C_3 for λ = 400 nm to 600 nm

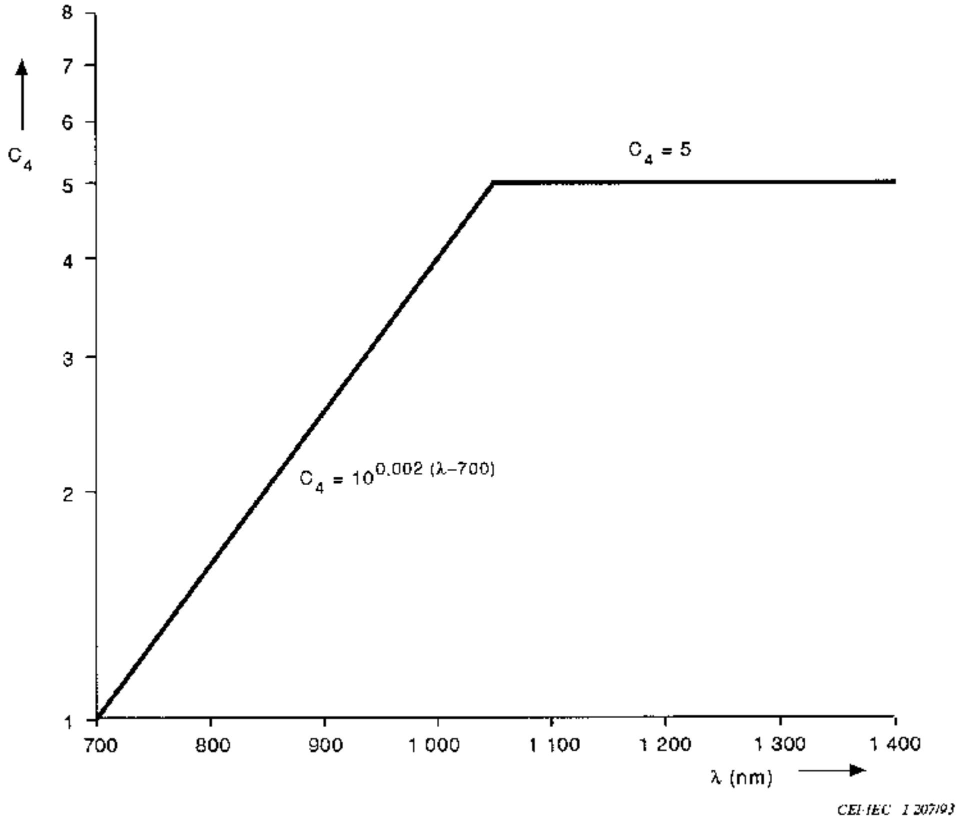

Figure 6 – Correction factor C_4 for λ = 700 nm to 1 400 nm