BRITISH STANDARD

BS EN 60825-1:1994

Incorporating Amendment Nos. 1, 2 and 3 and Corrigendum No. 1

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
Belgium
Denmark
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Luxembourg
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
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
Special announcement in *BSI News*, September 1994

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
15182	20 May 2004	Correction of date of withdrawal

ISBN 0 580 23532 7

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 corrigendum April 2004, 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 Please note that CENELEC amendment A11:1996 has been withdrawn.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.

The BSI copyright notice displayed in this document indicates when the document was last issued.

Sidelining in this document indicates the most recent changes by amendment.

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 60825-1

March 1994

+ A11
October 1996

+ A1
July 2002

+ A2
March 2001

UDC 621.375.826:620.1:614.8

Supersedes EN 60825:1991

Incorporates corrigendum February 1995 and April 2004

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) 2005-07-01

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

CONTENTS

SECTION THREE – USER'S GUIDE

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*

---

* 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

---

* 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 ($\geq$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

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 $\qquad E = \frac{d\Phi}{dA}$

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.)

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

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

where

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

$\mathrm{d}A$ 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: $\mathrm{W \cdot m^{-2} \cdot sr^{-1}}$

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.

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

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

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 $H = \frac{\mathrm{d}Q}{\mathrm{d}A} = \int E \mathrm{d}t$

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

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

Symbol: Φ, P $\Phi = \frac{\mathrm{d}Q}{\mathrm{d}t}$

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 $\qquad D = -\log_{10} \tau$

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

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

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

d) Non-circular and multiple sources

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

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.

$$\text{AEL}_{\text{train}} = \text{AEL}_{\text{single}} \times C_5$$

where

$\text{AEL}_{\text{train}}$ is the AEL for any single pulse in the pulse train;

$\text{AEL}_{\text{single}}$ 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:

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

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

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

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

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

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

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

c) Angle of acceptance

i) Photochemical retinal limits

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

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

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

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

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

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

ii) All other limits

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

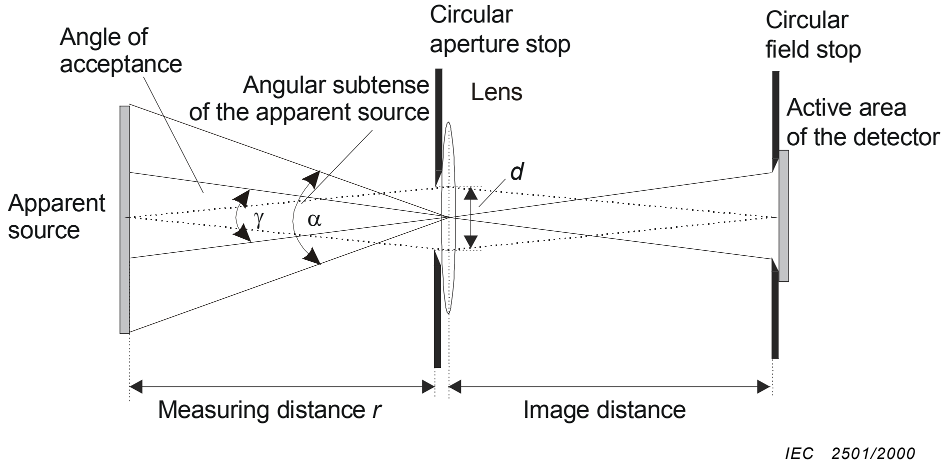


Figure 16a

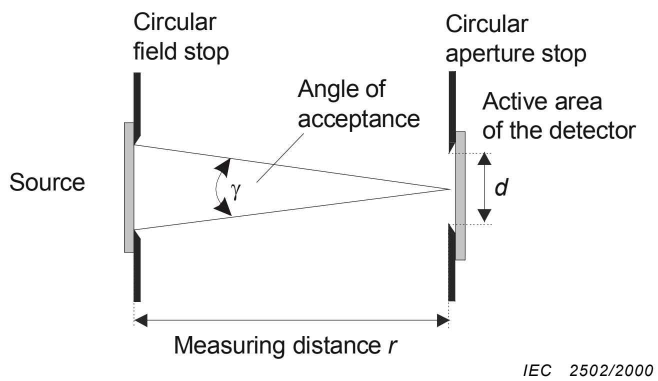


Figure 16b

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

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

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

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

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

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

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

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

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]

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

a For correction factors and units, see "notes to tables 1 to 4".

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

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	$5 \times 10^{-5}\ C_2$ 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	$3 \times 10^7\ C_4$ 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 are illustrated in figures 1 to 8.

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

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

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:

$$\mathrm{MPE}_{train} = \mathrm{MPE}_{single} \times C_5{}^{*}$$

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_i, these pulse groups are assigned pulse durations of T_i. For comparison with the MPE for the corresponding duration, all individual pulse radiant exposures are added.

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

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 s < $t \le 100$ s: $\gamma_p = 11$ mrad

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

for 10^4 s < $t \le 3 \times 10^4$ 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 $\alpha_{min} \leq \gamma \leq \alpha_{max}$ (see 8.4 d)).

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

13.5 Extended source lasers

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">($t \le T_1$)
C_1 J·m^{-2}
C_2 J·m^{-2}
($t > T_1$)</td><td colspan="4">C_2 J·m^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="6">C_1 J·m^{-2}</td><td colspan="2">10^4 J m^{-2}</td><td colspan="2">10 W m^{-2}</td></tr>
<tr><td rowspan="5">400 to 700[d]</td><td rowspan="5">$1,5 \times 10^{-4}$ C_6 J·m^{-2}</td><td rowspan="5">$2,7 \times 10^4$ $t^{0,75}$ C_6 J·m^{-2}</td><td colspan="2" rowspan="5">5×10^{-3} C_6 J·m^{-2}</td><td colspan="3" rowspan="5">18 $t^{0,75}$ C_6 J·m^{-2}</td><td rowspan="3">400 to 600 nm[d]</td><td colspan="4">Retinal photochemical hazard</td></tr>
<tr><td>100 C_3 J·m^{-2}
using
γ_p = 11 mrad</td><td colspan="2">1 C_3 W·m^{-2}
using
γ_p = 1,1 $t^{0,5}$ mrad</td><td>1 C_3 W·m^{-2}
using
γ_p = 110 mrad</td></tr>
<tr><td colspan="4">*AND*[d]</td></tr>
<tr><td rowspan="2">400 to 700 nm[d]</td><td colspan="4">Retinal thermal hazard</td></tr>
<tr><td colspan="4">$\alpha \le 1,5$ mrad: 10 W·m^{-2}
$\alpha > 1,5$ mrad: 18 C_6 $T_2^{-0,25}$ W·m^{-2}
($t > T_2$)
($t \le T_2$)
18 $t^{0,75}$ C_6 J·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">$\alpha \le 1,5$ mrad: 10 C_4 C_7 W·m^{-2}
$\alpha > 1,5$ mrad: 18 C_4 C_6 C_7 $T_2^{-0,25}$ W·m^{-2}
($t > T_2$)
($t \le T_2$)
18 $t^{0,75}$ C_4 C_6 C_7 J·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	**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)

Wave-length 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	3×10^{10} W·m^{-2}	30 J·m^{-2}				
302,5 to 315		C_1 J·m^{-2} (t > T_1) / C_2 J·m^{-2} (t > T_1)			C_2 J·m^{-2}	
315 to 400		C_1 J·m^{-2}			10^4 J·m^{-2}	10 W·m^{-2}
400 to 700	2×10^{11} W·m^{-2}	200 J·m^{-2}		$1{,}1\times10^4\ t^{0{,}25}$ J·m^{-2}	2 000 W·m^{-2}	
700 to 1 400	2×10^{11} C_4 W·m^{-2}	200 C_4 J·m^{-2}		$1{,}1\times10^4\ C_4\ t^{0{,}25}$ J·m^{-2}	2 000 C_4 W·m^{-2}	
1 400 to 1 500	10^{12} W·m^{-2}	10^3 J·m^{-2}		5 600 $t^{0{,}25}$ J·m^{-2}	1 000 W·m^{-2} 3)	
1 500 to 1 800	10^{13} W·m^{-2}	10^4 J·m^{-2}				
1 800 to 2 600	10^{12} W·m^{-2}	10^3 J·m^{-2}		5 600 $t^{0{,}25}$ J·m^{-2}		
2 600 to 10^6	10^{11} W·m^{-2}	100 J·m^{-2}		5 600 $t^{0{,}25}$ J·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·m^{-2}. Between 0,01 m^2 and 0,1 m^2, the MPE varies inversely proportional to the irradiated skin area.

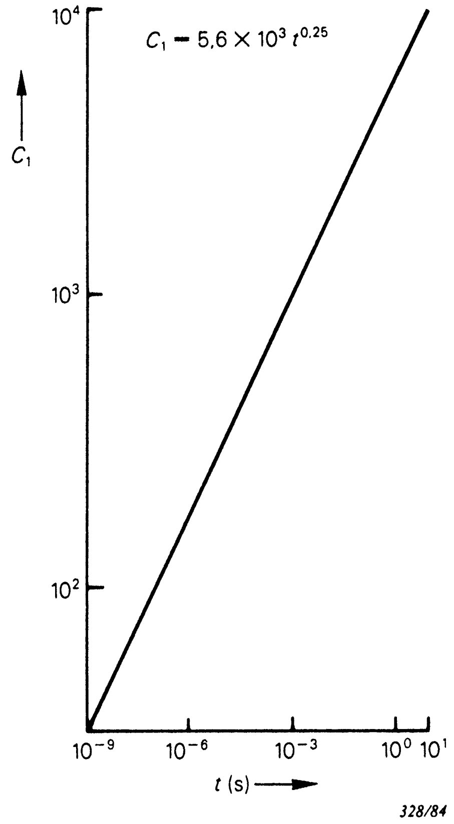


Figure 1 – Correction factor C_1 for emission durations from 10^{-9} s to 10 s

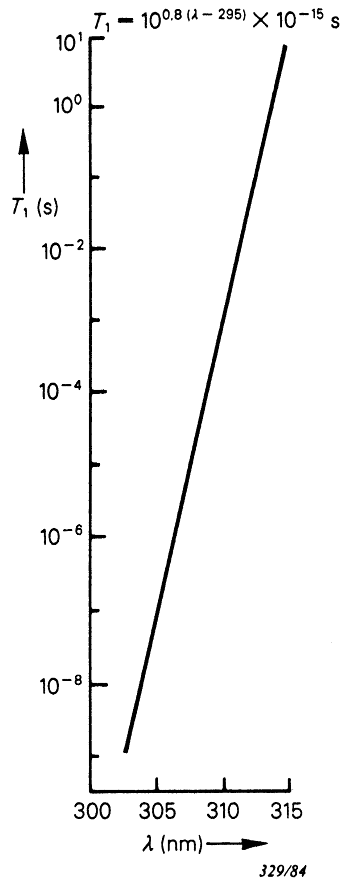


Figure 2 – Breakpoint T_1 for λ = 302,5 nm to 315 nm

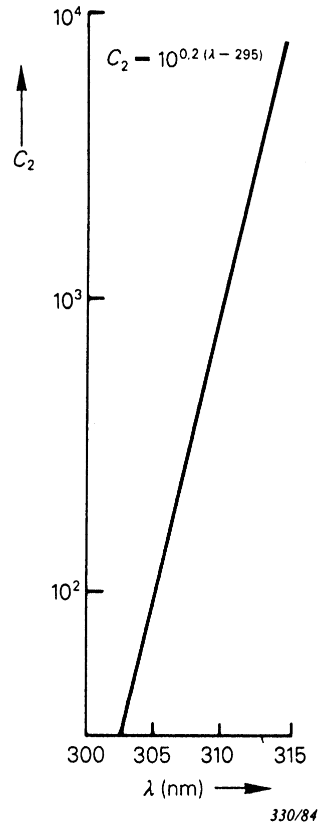


Figure 3 – Correction factor C_2 for λ = 302,5 nm to 315 nm

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

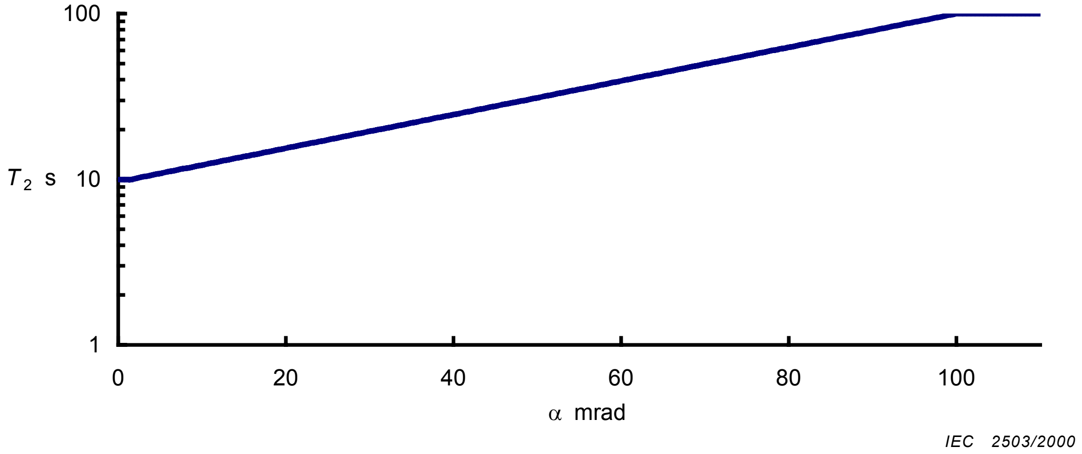


Figure 4 – Breakpoint T_2 for source size α ranging from 0 mrad to more than 100 mrad

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

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

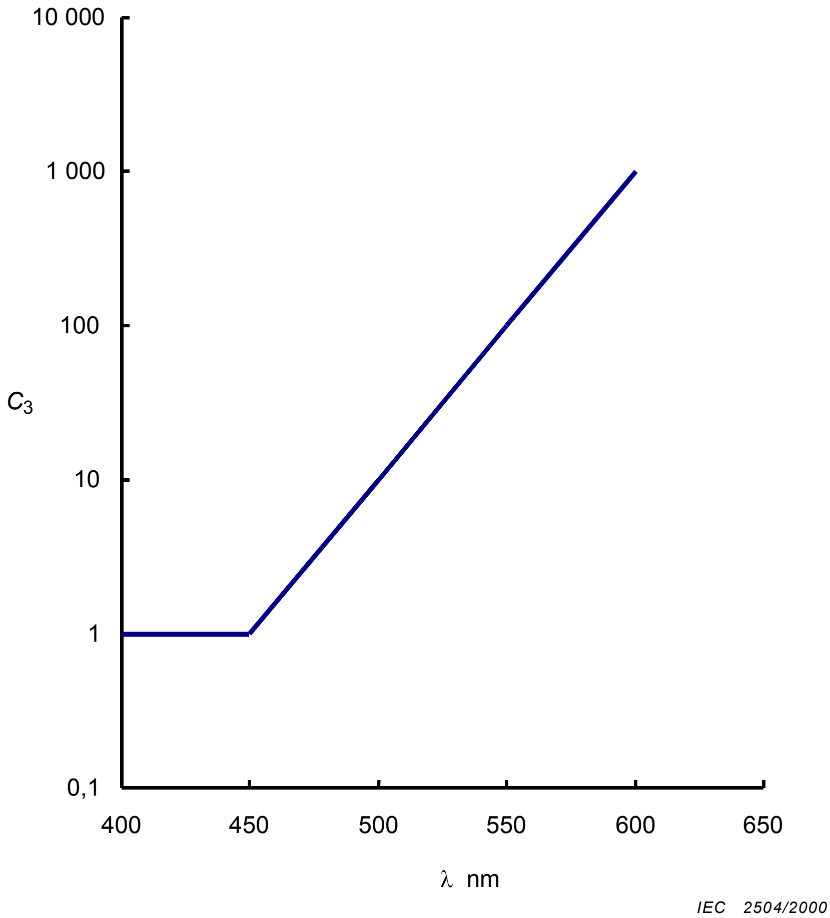


Figure 5 – Correction factor C_3 for λ = 400 nm to 600 nm

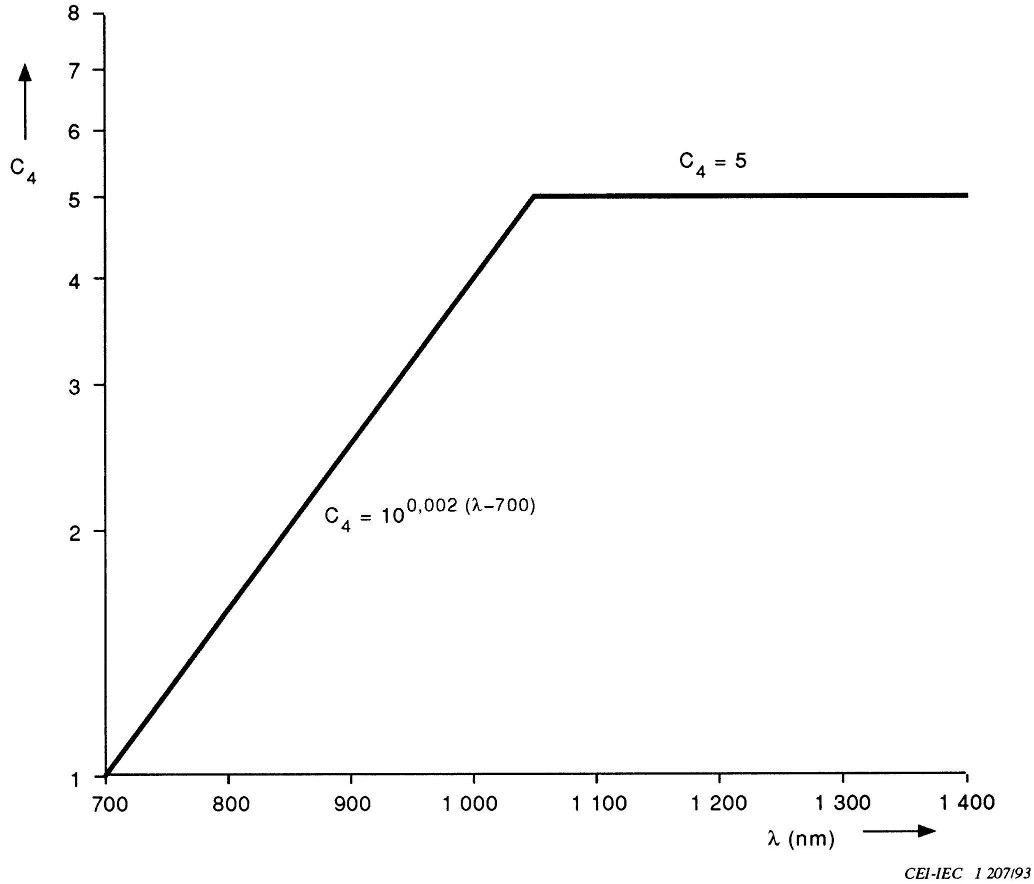


Figure 6 – Correction factor C_4 for λ = 700 nm to 1 400 nm

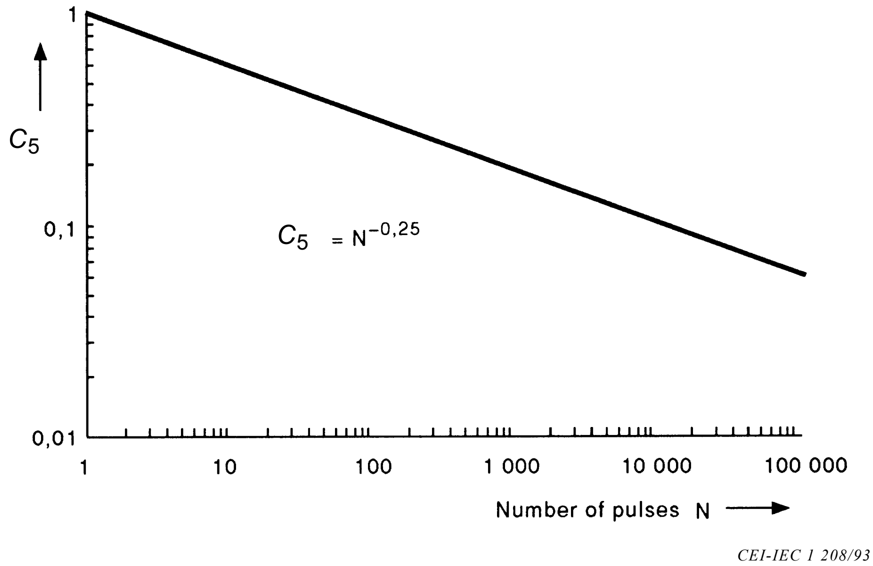


Figure 7 – Correction factor C_5 shown for N (number of pulses) between 1 and 100 000

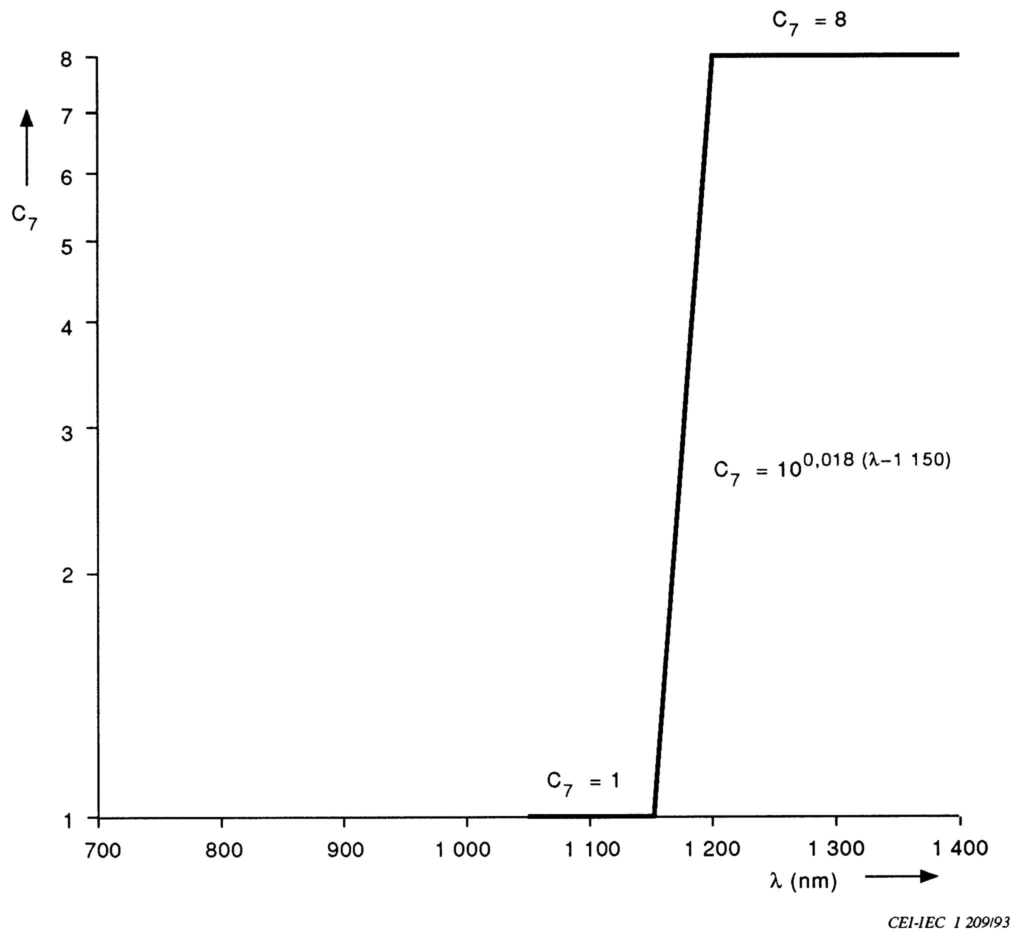


Figure 8 – Correction factor C_7 for λ = 1 050 nm to 1 400 nm

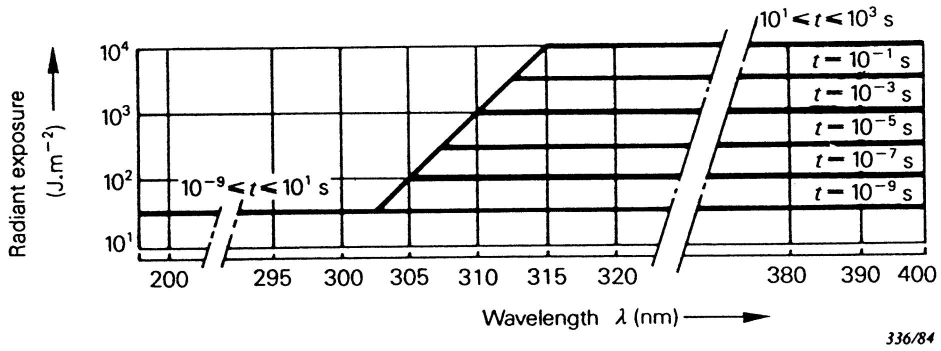


Figure 9a – MPE for direct ocular exposure to ultra-violet radiation at selected emission durations from 10^{-9} s to 10^3 s

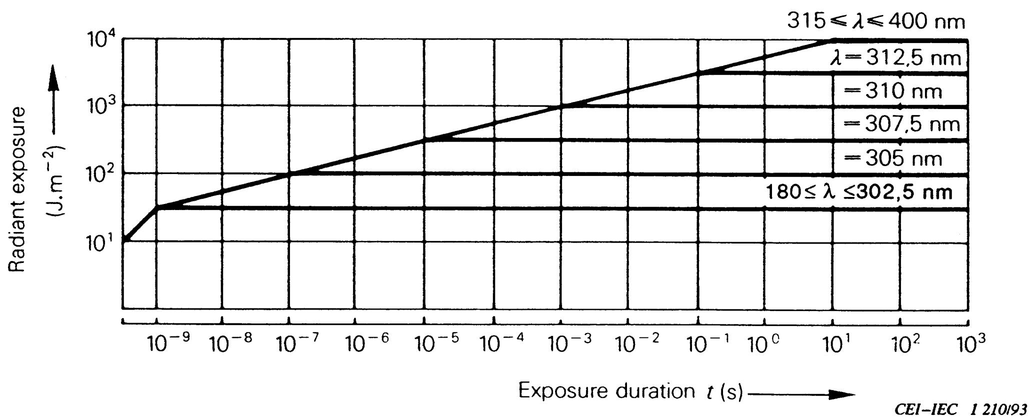


Figure 9b – MPE for direct ocular exposure to ultra-violet radiation for exposure durations from 10^{-9} s to 10^3 s at selected wavelengths

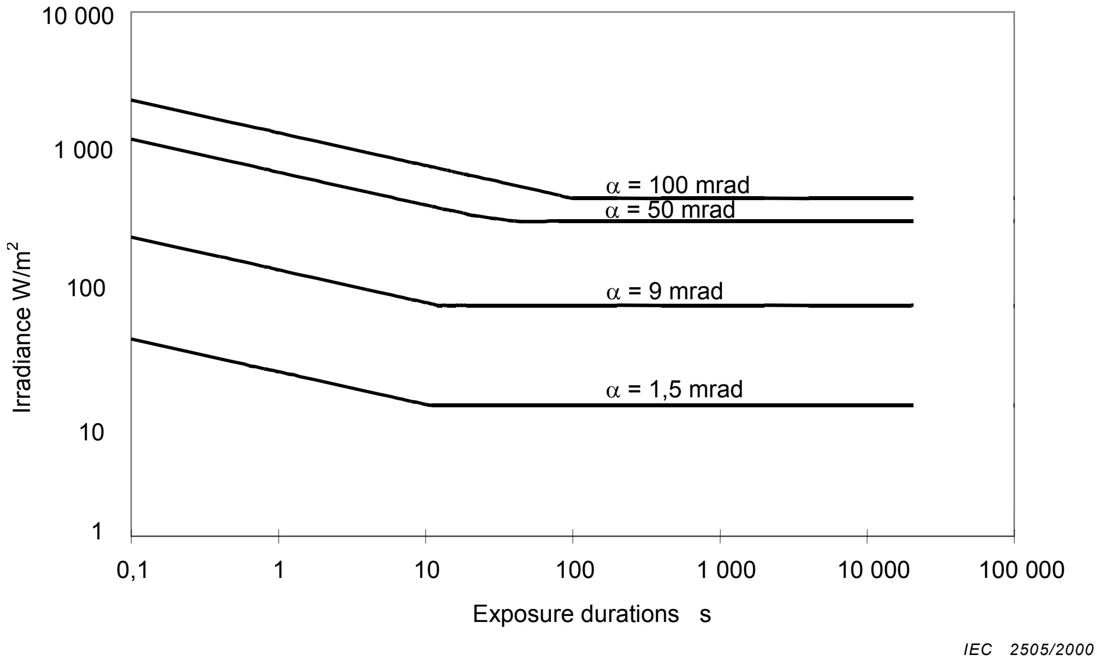


Figure 10a – MPE for direct ocular exposure to protect against thermal injury (λ = 400 nm to 700 nm) for exposure durations greater than 0,1 s for selected source sizes between 1,5 mrad and 100 mrad

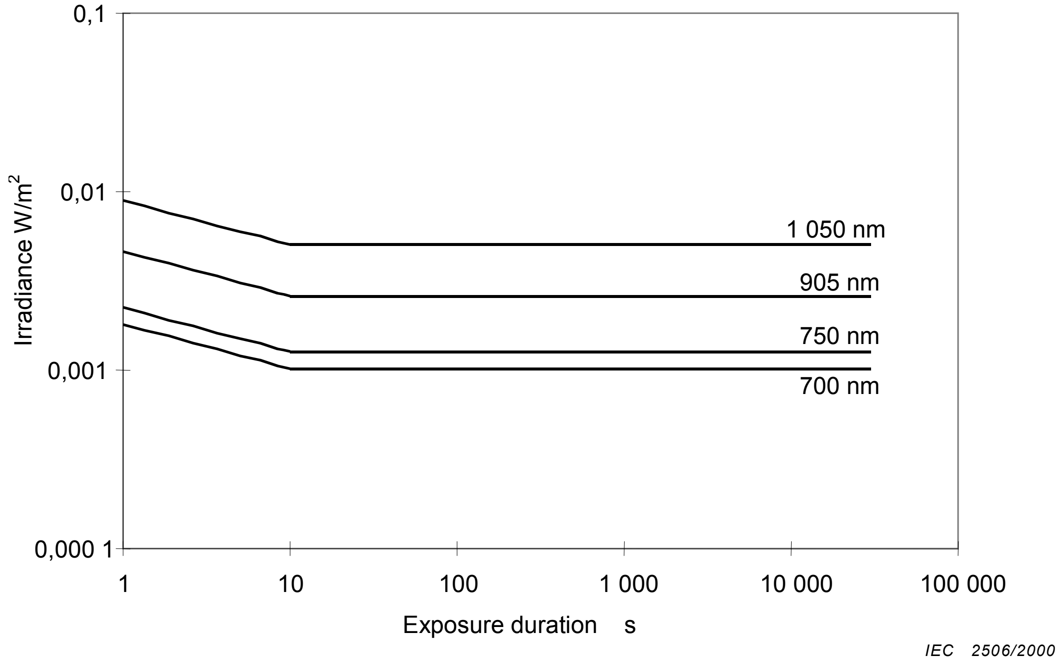
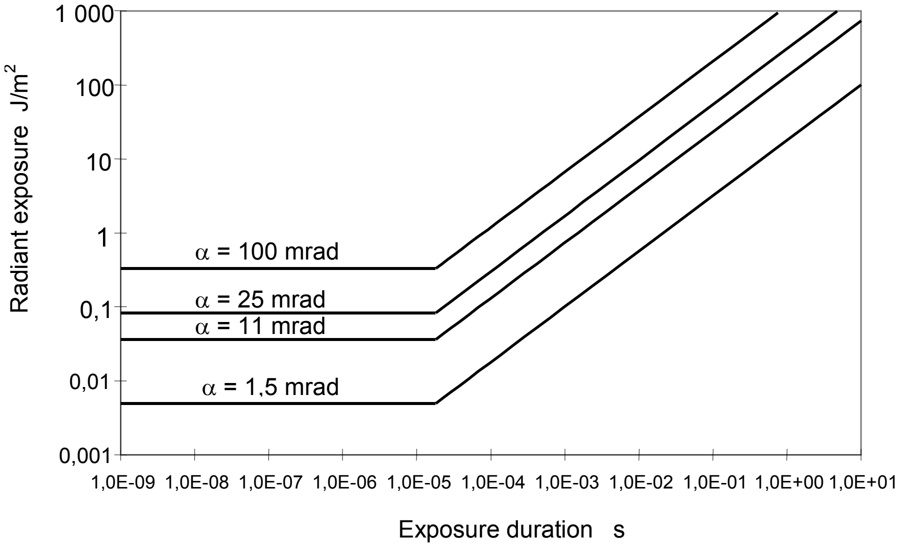
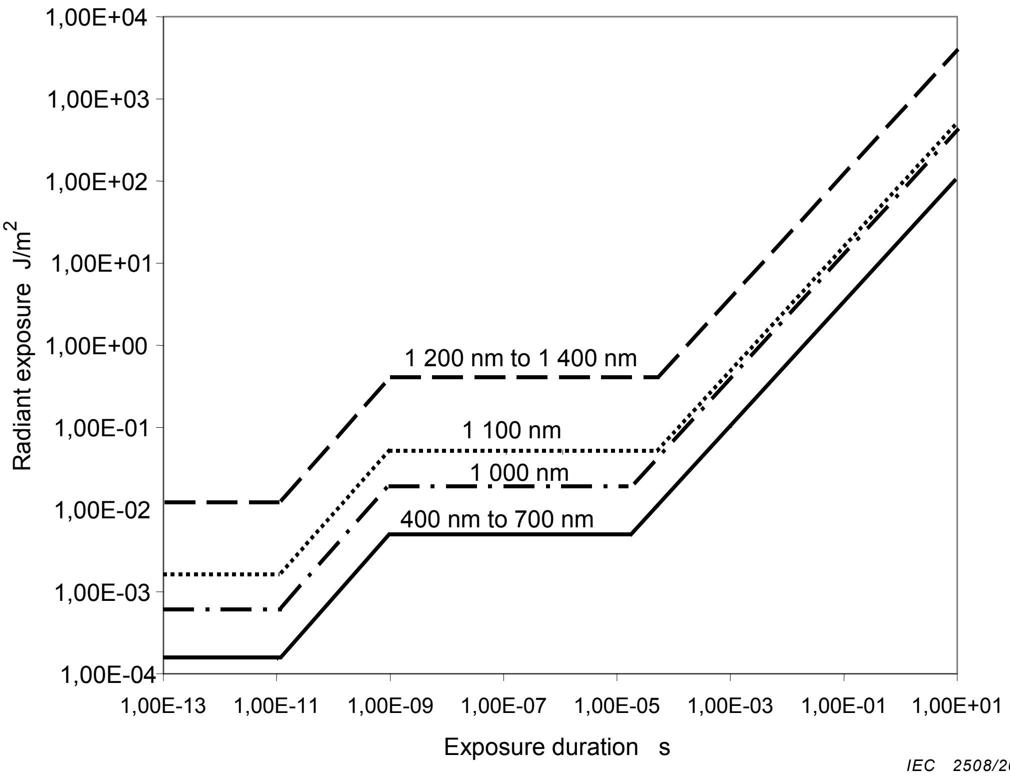


Figure 10b – MPE for direct ocular exposure (C_6 = 1) for exposure durations greater than 1 s for selected wavelengths between 700 nm and 1 050 nm



IEC 2507/2000

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



IEC 2508/2000

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

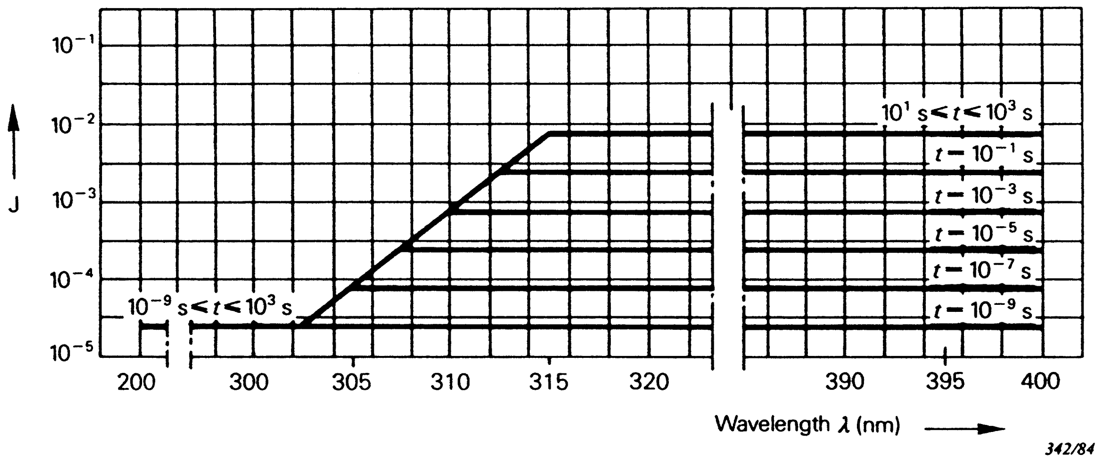


Figure 12a – AEL for Class 1 ultra-violet laser products for selected emission durations from 10^{-9} s to 10^{3} s

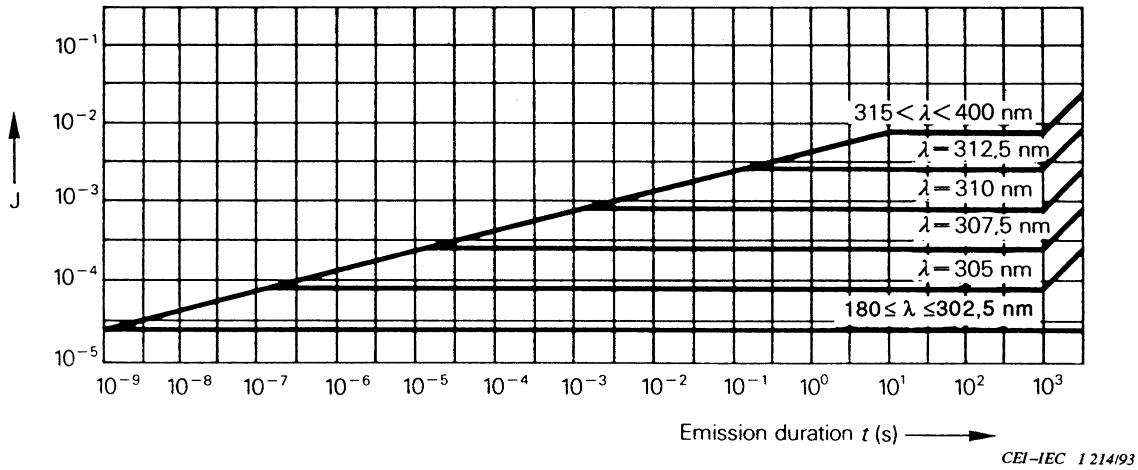


Figure 12b – AEL for Class 1 ultra-violet laser products for emission durations from 10^{-9} s to 10^{3} s at selected wavelengths

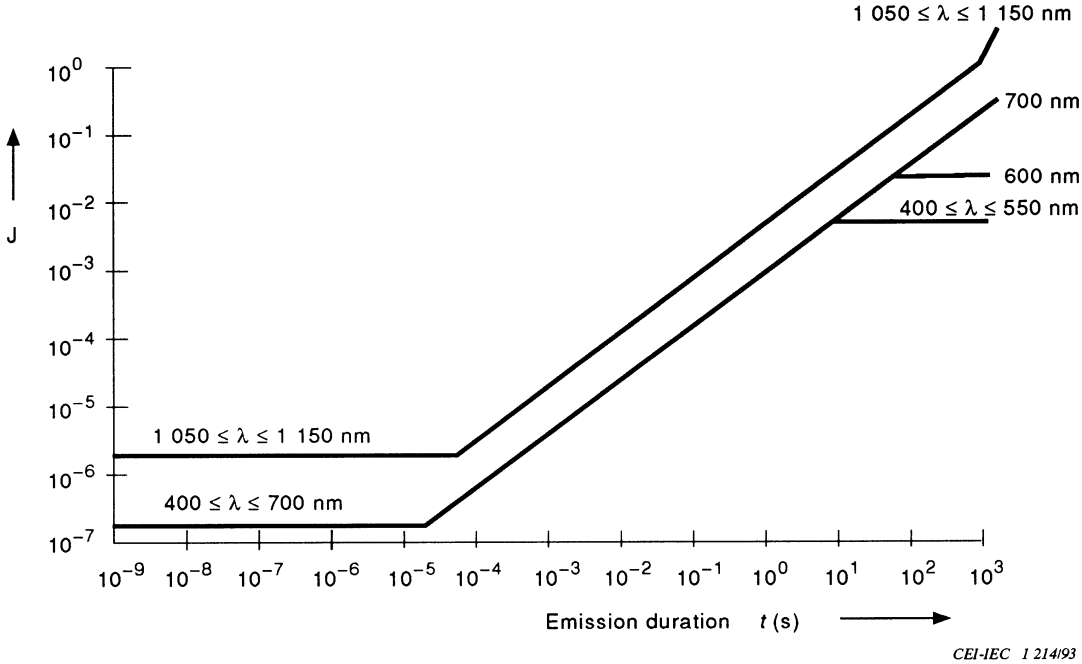
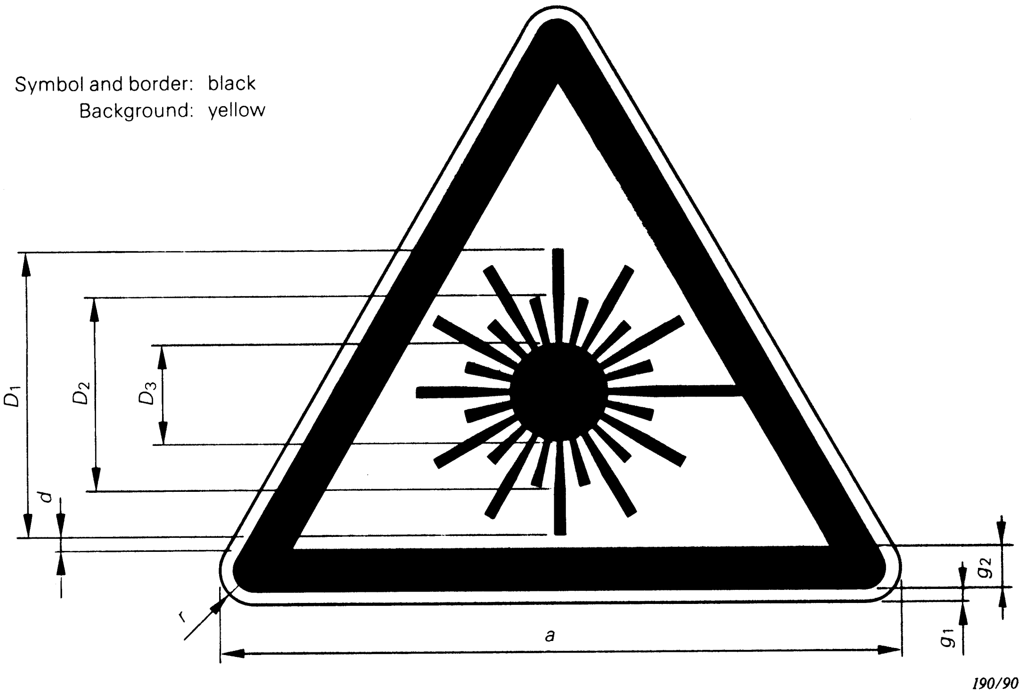


Figure 13 – AEL for Class 1 visible and selected infra-red laser products (case C_6 = 1)



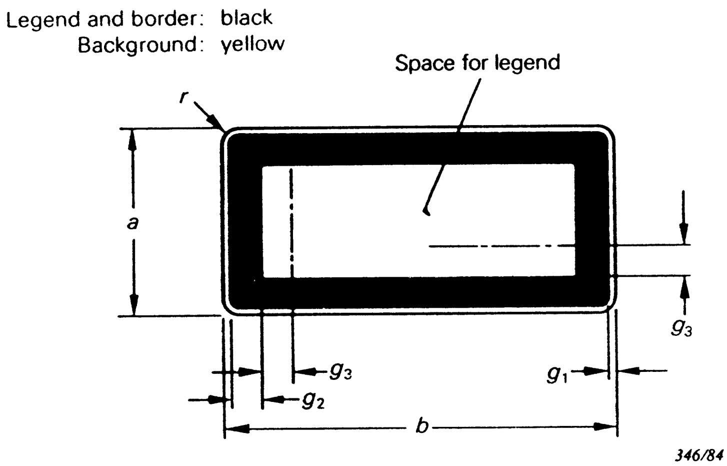
Dimensions in millimetres

a	g_1	g_2	*r*	D_1	D_2	D_3	*d*
25	0,5	1,5	1,25	10,5	7	3,5	0,5
50	1	3	2,5	21	14	7	1
100	2	6	5	42	28	14	2
150	3	9	7,5	63	42	21	3
200	4	12	10	84	56	28	4
400	8	24	20	168	112	56	8
600	12	36	30	252	168	84	12
The dimensions D_1, D_2, D_3, g_1 and *d* are recommended values.							

NOTE 1 The relationship between the greatest distance *L* from which the label can be understood and the minimum area *A* of the label is given by: $A = L^2/2\,000$, where *A* and *L* are expressed in square metres and metres respectively. This formula applies for distance *L* less than about 50 m.

NOTE 2 These dimensions are recommended values. As long as they are proportional to the values, the symbol and border may be of any legible size as required to suit the size of the laser product.

Figure 14 – Warning label – Hazard symbol



Dimensions in millimetres

a × **b**	g_1	g_2	g_3	*r*	**Minimum height of lettering**
26 × 52	1	4	4	2	Lettering shall be of a size which renders it legible
52 × 105	1,6	5	5	3,2	
84 × 148	2	6	7,5	4	
100 × 250	2,5	8	12,5	5	
140 × 200	2,5	10	10	5	
140 × 250	2,5	10	12,5	5	
140 × 400	3	10	20	6	
200 × 250	3	12	12,5	6	
200 × 400	3	12	20	6	
250 × 400	4	15	25	8	
The dimension g_1 is recommended.					

NOTE 1 The relationship between the greatest distance L from which the label can be understood and the minimum area A of the label is given by: $A = L^2/2\ 000$, where A and L are expressed in square metres and metres respectively. This formula applies for distance L less than about 50 m.

NOTE 2 These dimensions are recommended values. The label may be of any size necessary to contain the required lettering and border. The minimum width of each border dimension g_2 and g_3 shall be 0,06 times the length of the shorter side of the label.

Figure 15 – Explanatory label

Annex A
(informative)

Examples of calculations

Symbols used in the examples of this annex:

Symbol	Unit	Definition
a	m	Diameter of the emergent laser beam.
AEL	W, J, $W \cdot m^{-2}$ or $J \cdot m^{-2}$	Accessible emission limit.
α	rad	The angle subtended by an apparent source (or a diffuse reflection) as viewed at a point in space.
α_f	rad	Angle at the eye subtending the apparent source of radiation at a distance of r_f = 100 mm.
α_{min}	rad	Minimum angle subtended by a source for which the extended source criterion applies.
α_{max}	rad	The value of angular subtense of the apparent source above which the MPEs and AELs are independent of the source size. (α_{max} = 0,1 rad)
$C_1, C_2, \ldots, C_7$	1	Correction factors (see notes to tables 1 to 4)
d_u	m	Diameter of the smallest circle at a specified distance, r, from the apparent source that contains u % of the total laser power (or energy). In the case of a Gaussian beam, d_{63} corresponds to the points where the irradiance (or radiant exposure) falls to 1/e of its central peak value.
D_e	m	Diameter of the exit pupil of an optical system.
D_o	m	Diameter of the objective of an optical system.
η	1	Fraction of the total laser power (or energy) collected through a specified aperture located at a specified distance, r, from the apparent source.
F	Hz	Pulse repetition frequency.
G	1	Square root of the ratio of retinal irradiance or radiant exposure received by an optically aided eye to that received by an unaided eye.
H	$J \cdot m^{-2}$	Radiant exposure or
E	$W \cdot m^{-2}$	irradiance at a specified distance, r, from the apparent source.
H_o	$J \cdot m^{-2}$	Emergent beam radiant exposure or
E_o	$W \cdot m^{-2}$	irradiance at zero distance from the apparent source.
L_p	$J \cdot m^{-2} \cdot sr^{-1}$	Integrated radiance of an extended source.
λ	nm	Wavelength of laser radiation.
M	1	Magnification of an optical instrument.

Symbol	Unit	Definition
H_{MPE} or E_{MPE}	$J \cdot m^{-2}$ $W \cdot m^{-2}$	Maximum permissible exposure
μ	m^{-1}	Atmospheric attenuation coefficient at a specified wavelength.
N	1	Number of pulses contained within an exposure duration
NA	1	Numerical aperture of a laser source.
NA_m	1	Numerical aperture of a microscope objective
NOHD	m	Nominal ocular hazard distance.
OD	1	Optical (transmittance) density defined as the logarithm to base 10 of the reciprocal of the transmittance (see also IEV 845-04-66; symbol *D* is not used here to avoid confusion with diameters).
P_o	W	Total radiant power (radiant flux) of a CW laser, or average radiant power of a repetitively pulsed laser.
P_p	W	Radiant power within a pulse of a pulsed laser.
ϕ	rad	Divergence angle of an emergent laser beam.
π	1	The numerical constant 3,142.
Q	J	Total radiant energy of a pulsed laser.
r	m	Distance from the apparent source to the viewer, measurement aperture, or diffuse target.
r_1	m	Distance from the laser target to the viewer or measurement aperture.
$r_{1,max}$	m	Maximum distance from the laser target to the viewer where extended source viewing conditions apply.
t	s	Time duration of a single laser pulse.
T	s	Total exposure duration of a train of pulses.
T_1, T_2	s	Time breakpoints (see notes to tables 1 to 4).
w_o	µm	Mode field diameter for a single-mode optical fibre measured at the $1/e^2$ points of the optical power distribution (see also IEV 731-03-65)*.

* IEC 60050(731):1991, *International Electrotechnical Vocabulary (IEV) – Chapter 731: Optical fibre communication.*

A.1 Maximum permissible exposure (MPE) – Introduction

The maximum permissible exposure is defined in 3.51 as the maximum level of laser radiation to which living tissues (persons) may be exposed without suffering consequential injury either immediately after exposure, or later in time. Maximum permissible exposure values are set below known hazard levels. However, the MPE values should be regarded as guides for safe exposure, rather than as sharp dividing lines between safe and unsafe levels of exposure.

The MPE values are dependent upon:

- the wavelength of the radiation;
- the exposure time or pulse duration;
- the spectrum of wavelengths, when the tissue is exposed to more than one wavelength;
- the nature of the tissue exposed;
- the angular subtense of the source (which determines the size of the retinal image) in the wavelength range from 400 nm to 1 400 nm.

The examples presented in this annex illustrate the calculation procedures for intrabeam viewing, for diffuse reflections and extended sources, and for pulsed or modulated exposures. The examples show step-by-step calculation procedures for typical wavelengths and other exposure parameters. The user may then adapt these procedures to a specific situation when the calculation of the MPE is necessary.

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

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

Example A.2-1

Calculate the MPE for helium-cadmium laser, λ = 325 nm, with an emission duration of 0,1 s.

Solution:

The MPE values can be found in table 6. At the intersection of the wavelength range from 315 nm to 400 nm and exposure duration column 1×10^{-3} s to 10 s, the MPE is found to be equal to C_1 J·m^{-2}. C_1 can be calculated from the formula given in the notes to tables 1 to 4.

$$C_1 = 5{,}6 \times 10^3 \times t^{0{,}25}$$

$$H_{MPE} = 5{,}6 \times 10^3 \times 0{,}1^{0{,}25}\ \mathrm{J{\cdot}m^{-2}} = 3{,}15 \times 10^3\ \mathrm{J{\cdot}m^{-2}}$$

In terms of irradiance obtained after dividing by t,

$$E_{MPE} = 3{,}15 \times 10^4\ \mathrm{W{\cdot}m^{-2}}.$$

Example A.2-2

Determine the maximum permissible single pulse exposure for a pulsed ruby laser, λ = 694 nm, with an exposure duration of 10^{-3} s.

Solution:

In table 6, the MPE is found at the intersection of the wavelength range from 400 nm to 700 nm and exposure duration $t = 5 \times 10^{-5}$ s to 10^{-3} s. The MPE value then is

$$H_{\mathrm{MPE}} = 18 \times t^{0,75} \times C_6 \ \mathrm{J{\cdot}m^{-2}}.$$

For intrabeam viewing of a small source, $\alpha \le \alpha_{\mathrm{min}}$, and $C_6 = 1$ (see notes to tables 1 to 4).

Thus,

$$H_{\mathrm{MPE}} = 18 \times (10^{-3})^{0,75} \times 1 \ \mathrm{J{\cdot}m^{-2}} = 0,10 \ \mathrm{J{\cdot}m^{-2}}$$

Example A.2-3

What is the MPE for a single-pulse of a gallium-arsenide laser, $\lambda = 905$ nm, with a pulse width of 100 ns?

Solution:

In table 6, the MPE is found at the intersection of the wavelength range from 700 nm to 1 050 nm and exposure duration $t = 10^{-7}$ s to $1,8 \times 10^{-5}$ s. The MPE expressed as a radiant exposure is given by

$$H_{\mathrm{MPE}} = 5 \times 10^{-3} \times C_4 \times C_6 \ \mathrm{J{\cdot}m^{-2}}.$$

The coefficient C_4 can be calculated from the formula given in the notes to tables 1 to 4:

$$C_4 = 10^{0,002(\lambda - 700)} = 2,57$$

Since $C_6 = 1$ (small source viewing conditions),

$$H_{\mathrm{MPE}} = 5 \times (10^{-3}) \times 2,57 \times 1 \ \mathrm{J{\cdot}m^{-2}} = 12,9 \times 10^{-3} \ \mathrm{J{\cdot}m^{-2}}$$

Example A.2-4: Complex laser diode array source

Find the MPE applicable to intrabeam viewing for a 10 s exposure at a distance of 1 m from a complex Ga-As (905 nm) laser diode array source. The source consists of two rows of 10 diodes each that are mounted behind collimating optics. The source has an output power of 6 W and a pulse repetition frequency F of 12 kHz. The pulse duration is 80 ns. The exit aperture (collimating lens) is 5 cm in diameter and the emergent beam diameter is 3,5 cm at the 1/e peak irradiance points (i.e., a 3,5 cm circular measurement aperture would collect 63 % of the beam power). The axial beam irradiance (average) at a distance of 1 m is $3,6 \times 10^3$ W·m^{-2}. The beam divergence is 25 mrad horizontally by 3 mrad vertically, and at a distance of 1 m from the exit aperture, the beam size is approximately 3,0 cm by 3,8 cm, respectively.

An intrabeam photograph (using infrared film) taken at a distance of 1 m from the exit aperture reveals that each diode subtends a projected line image 2,2 mrad long and less than 0,5 mrad across. Each diode is separated by an angle of 3,0 mrad centre-to-centre, and the two rows are separated by an angle of 2,3 mrad (see figure A.1). Using an infrared image converter with an OD 4 filter to reduce glare, it is revealed that these angular separations are constant from all viewing distances between 10 cm and 2 m (this behaviour is explained in chapter 15 of Sliney and Wolbarsht, *Safety with Lasers and other Optical Sources*, New York: Plenum Publishing Co., 1980).

Solution

The MPE applicable to the laser diode array is the most restrictive MPE resulting from an evaluation of each individual source and each possible grouping of the array of diodes. However, the evaluation can be greatly simplified by using the conservative assumption that all the radiant power originates from a single point source. This would always overstate the hazard, and if it did not result in overly restrictive control measures, the more complex analysis of the extended source would not have to be performed.

The determination of the applicable (most restrictive) MPE requires a trial-and-error approach, since the MPE for a single diode, two adjacent diodes, a group of three or four, etc., and the entire array is to be calculated; recognizing that in each case the power or energy is averaged over the angular subtense α applicable to that grouping. It is useful to draw a map of the source to study different combinations of diodes (see figure A.1). The total number of pulses N in a 10 s exposure is 120 000.

The single pulse MPE for the multiple-pulse assessment is given by (using table 6 for an 80 ns pulse) the following:

$$\begin{aligned} H_{\mathrm{MPE,train}} &= C_5 \times 5 \times 10^{-3}\ C_4 C_6\ \mathrm{J{\cdot}m^{-2}} \\ &= 120\ 000^{-0,25} \times 5 \times 10^{-3} \times 2,57\ C_6\ \mathrm{J{\cdot}m^{-2}} \\ &= 6,9 \times 10^{-4}\ C_6\ \mathrm{J{\cdot}m^{-2}} \end{aligned}$$

In order to compare the single pulse MPE with the average irradiance of the beam, it is convenient to express the above MPE (expressed in terms of radiant exposure) as an irradiance averaged over F pulses per second as follows:

$$\begin{aligned} E_{\mathrm{MPE,train,F}} &= H_{\mathrm{MPE,train}} \times F \\ &= 6,9 \times 10^{-4}\ C_6\ \mathrm{J{\cdot}m^{-2}} \times 1,2 \times 10^4\ \mathrm{Hz} \\ &= 8,28\ C_6\ \mathrm{W{\cdot}m^{-2}} \end{aligned}$$

The single pulse MPE for the average power assessment is given by (using table 6 for a 10 s exposure) the following:

$$\begin{aligned} H_{\mathrm{MPE,avg}} &= 18 \times t^{0,75}\ C_4\ C_6\ \mathrm{J{\cdot}m^{-2}} \\ &= 18 \times 10^{0,75} \times 2,57\ C_6\ \mathrm{J{\cdot}m^{-2}} \\ &= 260 \times C_6\ \mathrm{J{\cdot}m^{-2}} \end{aligned}$$

The above MPE, expressed as a radiant exposure, can also be expressed as an irradiance averaged over the 10 s exposure as follows:

$$\begin{aligned} E_{\mathrm{MPE,avg}} &= H_{\mathrm{MPE,avg}}/t \\ &= 260 \times C_6\ \mathrm{J{\cdot}m^{-2}}\ /(10\ \mathrm{s}) \\ &= 26 \times C_6\ \mathrm{W{\cdot}m^{-2}} \end{aligned}$$

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

Single-diode group

The individual diodes subtend angles of 0,5 mrad (vertical) and 2,2 mrad (horizontal). The MPE for rectangular sources is determined by the arithmetic mean of the two angular subtenses. As stated in 13.4.2, before determining the mean, any angular subtense less than 1,5 mrad or greater than 100 mrad should be replaced by 1,5 mrad or 100 mrad, respectively. Therefore the mean is as follows:

$$(1{,}5 + 2{,}2)/2 \text{ mrad} = 1{,}85 \text{ mrad}$$

This value is greater than 1,5 mrad, thus the individual diode is considered to be an extended source and the correction factor is C_6 = 1,85/1,5 = 1,23. The applicable MPE is as follows:

$$E_{\mathrm{MPE,diode}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 1{,}23 \text{ W·m}^{-2} = 10{,}2 \text{ W·m}^{-2}$$

This MPE is not applicable to the total irradiance, but rather the irradiance of each single diode. Assuming that all diodes have the same power emission, this MPE has to be compared with the total irradiance divided by the number of diodes, i.e. 20.

$$E_{\mathrm{diode}} = E_{\mathrm{total}} /20 = 3\,600/20 \text{ W·m}^{-2} = 180 \text{ W·m}^{-2}$$

This MPE is exceeded at a distance of 1 m by a factor of 180/10,2 = 17,6.

Horizontal two-diode group

A plausible group of the array to consider is two horizontally adjacent diodes subtending angles of 0,5 mrad (vertical) by 5,2 mrad (horizontal). Replacing 0,5 mrad by 1,5 mrad as stated in 13.4.2, the arithmetic mean of the two angular dimensions is (1,5 + 5,2)/2 mrad = 3,35 mrad. The correction factor is C_6 = 3,35/1,5 = 2,23 and the applicable MPE is as follows:

$$E_{\mathrm{MPE,hor,two}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 2{,}23 \text{ W·m}^{-2} = 18{,}5 \text{ W·m}^{-2}$$

Since the irradiance of this grouping is twice the irradiance of the single diode, this MPE has to be compared with the following:

$$E_{\mathrm{two}} = E_{\mathrm{diode}} \times 2 = 180 \times 2 \text{ W·m}^{-2} = 360 \text{ W·m}^{-2}$$

At a distance of 1 m, the hazard factor is 360/18,5 = 19,5. Hence, this grouping of two diodes produces a greater hazard factor (i.e. a more conservative MPE) than the single-diode group.

Vertical two-diode group

Another sub-unit of the array to consider is two vertical diodes subtending angles of 2,8 mrad (vertical) by 2,2 mrad (horizontal). The arithmetic mean of the two angular dimensions is 2,5 mrad. Hence the correction factor is C_6 = 2,5/1,5 = 1,67. The applicable MPE is as follows:

$$E_{\mathrm{MPE,vert,two}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 1{,}67 \text{ W·m}^{-2} = 13{,}8 \text{ W·m}^{-2}$$

The irradiance of this grouping is twice the irradiance of the single diode. Hence this MPE has to be compared with the following:

$$E_{\mathrm{two}} = E_{\mathrm{diode}} \times 2 = 180 \times 2 \text{ W·m}^{-2} = 360 \text{ W·m}^{-2}$$

At a distance of 1 m, the hazard factor is 360/13,8 = 26,1. Hence, this grouping produces a greater hazard factor than the previous one.

Four-diode group

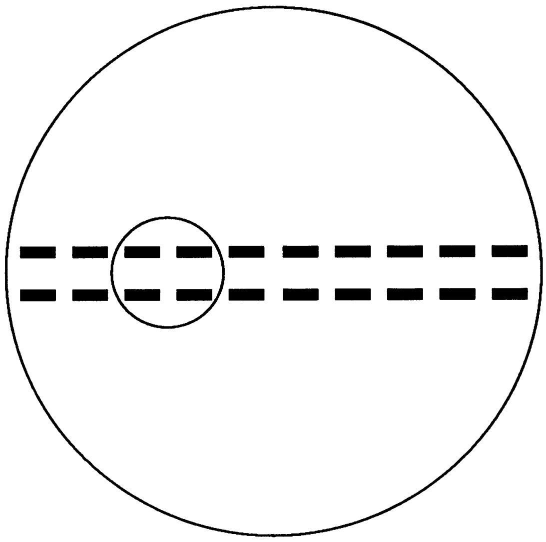
Another plausible sub-unit of the array to consider is four adjacent diodes (2 by 2) subtending angles of 2,8 mrad (vertical) by 5,2 mrad (horizontal). The arithmetic mean of the two angular dimensions is 4 mrad. Hence the correction factor is C_6 = 4/1,5 = 2,67. The applicable MPE is as follows:

$$E_{\mathrm{MPE,four}} = E_{\mathrm{MPE,train,F}} = 8{,}28 \times 2{,}67\ \mathrm{W \cdot m^{-2}} = 22{,}1\ \mathrm{W \cdot m^{-2}}$$

Since the irradiance of this grouping is four times the irradiance of the single diode, this MPE has to be compared with the following:

$$E_{\mathrm{four}} = E_{\mathrm{diode}} \times 4 = 180 \times 4\ \mathrm{W \cdot m^{-2}} = 720\ \mathrm{W \cdot m^{-2}}$$

At a distance of 1 m, the hazard factor is 720/22,1 = 32,5. This grouping produces a hazard factor greater than all the previous ones.



CEI 1 216/93

Figure A.1 – Laser diode array with two groupings

One row of 10 diodes

Another interesting grouping to evaluate is one entire row of 10 diodes subtending angles of 0,5 mrad (vertical) and 29,2 mrad (horizontal). Replacing 0,5 mrad by 1,5 mrad, as stated in 13.4.2, the arithmetic mean of the two angular dimensions is (1,5 + 29,2)/2 mrad = 15,3 mrad. Hence the correction factor is C_6 = 15,3/1,5 = 10,2.

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

Since this grouping contains 10 diodes, this MPE has to be compared with the following:

$$E_{\mathrm{ten}} = E_{\mathrm{diode}} \times 10 = 180 \times 10\ \mathrm{W \cdot m^{-2}} = 1\ 800\ \mathrm{W \cdot m^{-2}}$$

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

20-diode group

The last grouping to be considered in this example is an evaluation of the entire array of 20 diodes. Since the diodes are arranged in two adjacent rows, the vertical angular subtense is identical to that in the four-diode group, i.e. 2,8 mrad, and the horizontal angular subtense is 29,2 mrad. The average is 16 mrad, the correction factor is C_6 = 16/1,5 = 10,7 and the applicable MPE is as follows:

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

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

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

Additional remarks

It is important to note that in other situations the limiting case could be obtained from a grouping of a part of the source, not by the group of entire source. For example, we can consider another array constituted by twenty diodes arranged in two rows of 10 diodes each, with the same angular dimensions of the diodes and the same vertical distances as in the example described above, but with a horizontal centre-to-centre distance of 6 mrad.

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

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

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

Thus, C_6 = 11,5/1,5 = 7,67. The angular subtense of this group is (2,8 + 20,2)/2 = 11,5. Thus, C_6 = 11,5/11 = 1,05. Hence, the applicable MPE is as follows:

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

This value should be compared with the following:

$$E_{\mathrm{eight}} = E_{\mathrm{diode}} \times 8 = 180 \times 8\ \mathrm{W \cdot m^{-2}} = 1\ 440\ \mathrm{W \cdot m^{-2}}$$

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

The fact that the whole array gives a hazard factor smaller than the hazard factor of the eight-diode group does not mean that the whole array, i.e. the assembly of 20 diodes, is less hazardous than the assembly of eight diodes. The meaning of this apparently strange result is that, in this specific case, the correct evaluation of the hazard is not obtained by considering the 20 diodes as one uniform source subtending an angular subtense of 29,5 mrad, but is given by the analysis of the parts that form the array itself. This is due to the fact that the whole source is not uniform.

Required optical density

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

In general, it is also necessary to ensure that the filter can withstand the level of radiation power because, although the filter may have a sufficient optical density, it might be damaged by the radiation, and thus lose its capability to protect.

Using the simplistic approach of a point source approximation instead of the group calculations, the MPE for the entire array would be equal to 8,28 $W \cdot m^{-2}$. Thus, at a distance of 1 m, the point source approximation results in the irradiance exceeding the MPE by 3 600/8,28 = 435 times, requiring an OD of log 435 = 2,64 or more. Notice that the point source approximation results in the hazard being estimated at more than four times the hazard obtained by the more accurate approach of grouping diodes.

Use of an optical device

Normal telescopes and binoculars cannot focus objects at a distance of 1 m. However, for the purpose of this example, the use of a 3×-power device to view the laser at 1 m is considered. This requires the following additional analysis.

The aperture of this device is 21 mm, smaller than the dimensions of the beam. Therefore the power is increased by a factor of $3^2 = 9$. The angular dimensions of the array are increased by a factor of 3 due to the magnification of the 3×-power device. Hence, it is necessary to perform the calculation as previously reported, but taking into consideration new values for the angular dimensions and the power of each grouping.

Since the measurement method requires a maximum acceptance angle of α_{max} = 100 mrad to collect the radiation (see 8.4 d)), when one of the two angular dimensions of the grouping, e.g. the horizontal one (indicated by α_{hor}), is greater than α_{max}, the power of the grouping should be reduced to a factor of $\alpha_{max}/\alpha_{hor}$, to exclude the part of the source which is outside the acceptance angle. Furthermore, any angular subtense should be limited to α_{max} before determining the arithmetic mean to be used for the calculation of C_6, as stated in 13.4.2. However in this specific example, all the angular subtenses are less than α_{max}.

Considering the aided viewing with this optical device, the analysis of the different diode groups shows that the highest value of the hazard factor is given by the group of the whole array of 20 diodes. This value is 122, requiring an additional optical density of log 122 = 2,1.

It should be noted that in other situations the evaluation is simpler when the source is uniform, when the beam is larger than the aperture of the 3×-power optical device and when the angular subtenses of each grouping (the whole array included) are between α_{min} and α_{max} for both the aided and unaided viewing. In fact, in this case the optics would collect about nine times as much power, but the source would appear three times larger. Hence, since the factor C_6 is three times greater, the hazard produced by this optical device should be three times the hazard of the unaided viewing.

In this specific case, even if the source is not uniform, the hazard factor is about three times the hazard factor for unaided viewing. However, in other cases, the results could be very different.

Normally binoculars have a transmission of about 70 % at this wavelength, supplying 0,15 of this additional optical density. Hence, the necessary optical density with 3×-power optics is: OD = 2,1 – 0,15 = 1,95. Thus, an OD of 1,95 or more would provide protection for both aided and unaided direct intra-beam viewing at a distance of 1 m from the exit aperture.

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

Examples of extended source viewing are:

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

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

Example A.3-1

The radiation from a Q-switched Nd-YAG laser (λ = 1 064 nm, $t = 10^{-8}$ s) is expanded to form a beam 2 cm in diameter before being reflected from a perfect diffuser.

a) What is the range over which extended source viewing conditions exist?
b) What is the MPE at a distance of 2,5 m from the diffuser?

Solution:

The angular subtense is defined by the equation:

$$\alpha = 2 \arctan \frac{d_{63}}{2r_1} \simeq \frac{d_{63}}{r_1}$$

where d_{63} is the diameter of the laser beam at the diffusing target.

a) In the limiting case $\alpha = \alpha_{min}$ and, therefore,

$$r_{1,max} = \frac{d_{63}}{\alpha_{min}}$$

For this example

$$r_{1,max} = \frac{0{,}02 \text{ m}}{1{,}5 \times 10^{-3} \text{ rad}} = 13{,}3 \text{ m}$$

At distances greater than $r_{1,max}$ = 13 m, small source viewing conditions exist.

The MPE for the specified exposure duration is given by (see table 6):

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

where

C_7 = 1 for λ = 1 064 nm (see notes to tables 1 to 4). For the small source viewing situation, $\alpha \leq \alpha_{min}$, C_6 = 1, and the MPE is

$$H_{MPE} = 5 \times 10^{-2} \times 1 \times 1 \text{ J·m}^{-2} = 5 \times 10^{-2} \text{ J·m}^{-2}$$

b) At distances less than $r_{1,max}$ = 13 m, extended source viewing conditions exist, and $C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$ = 0,1 rad. At the distance of r_1 = 2,5 m,

$$\alpha = \frac{d_{63}}{r_1} = \frac{0{,}020\ \text{m}}{2{,}5\ \text{m}} = 8 \times 10^{-3}\ \text{rad}$$

and
$$C_6 = \frac{\alpha}{\alpha_{min}} = \frac{8{,}0 \times 10^{-3}\ \text{rad}}{1{,}5 \times 10^{-3}\ \text{rad}} = 5{,}33$$

Hence, the MPE for viewing of the extended source at 2,5 m is

$$H_{MPE} = 5 \times 10^{-2} \times 5{,}33 \times 1\ \text{J·m}^{-2} = 0{,}27\ \text{J·m}^{-2}.$$

Example A.3-2

Find the maximum radiant energy from the laser in example A.3-1 permitting non-hazardous viewing of the output reflected from a perfect diffuser located less than 0,2 m from the observer's eye.

Solution:

At distances less than 0,20 m, the viewing conditions are such that the acceptance angle α is greater than α_{max} = 0,1 rad:

$$\alpha = \frac{d_{63}}{r_1} = \frac{0{,}020\ \text{m}}{0{,}20\ \text{m}} = 0{,}10\ \text{rad}$$

The incident beam radiant exposure capable of producing a hazardous diffuse reflection under this extended source viewing condition can be obtained by first expressing the diffuse reflection MPE as an integrated radiance. This is accomplished by dividing the diffuse reflection MPE expressed as a radiant exposure by the solid angle formed by the maximum angle of acceptance. Where the maximum angle of acceptance, α_{max}, is 0,1 rad corresponding to a solid angle, Ω, given by $\Omega \approx \pi\ (\alpha_{max}/2)^2 = 7{,}85 \times 10^{-3}$ sr

and the diffuse reflection MPE expressed as an integrated radiance is

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

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

The integrated radiance MPE for this problem is obtained by substituting the small source MPE obtained in example A.3-2:

$$L_{MPE} = 8{,}5 \times 10^3 \times 5{,}0 \times 10^{-2}\ \text{J·m}^{-2}\text{·sr}^{-1} = 425\ \text{J·m}^{-2}\text{·sr}^{-1}$$

The integrated radiance of the diffuse reflection is related to the incident beam radiant exposure at the target through the expression:

$$H = \pi \times L_p$$

Hence, the radiant exposure sufficient to produce a hazardous reflection from a 100 % reflectance, white diffuse target is

$$H_{MPE} = \pi\ \text{sr} \times L_{MPE}\ \text{J·m}^{-2}\text{·sr}^{-1} = 1{,}34 \times 10^3\ \text{J·m}^{-2}$$

Finally, assuming that the radiant energy is uniformly distributed over the area of the target beam spot, A, the radiant energy sufficient to produce a hazardous reflection is

$$Q_{MPE} = H_{MPE} \times A = H_{MPE} \times \pi/4 \times d_{63}^2 \qquad = 1{,}34 \times 10^3 \times \pi/4 \times 0{,}02^2 \text{ J} = 0{,}42 \text{ J}$$

Example A.3-3

Calculate the minimum safe viewing distance normal to a perfect diffusing screen if the output from the laser in example A.3-2 is focused on the screen.

Solution:

In this situation, the radiation is reflected hemispherically outward from the focal point on the diffuse Lambertian target; therefore, small source viewing conditions apply. At a distance r_1 from a Lambertian source, the radiant exposure is given by:

$$H = \left(\frac{Q \cos \theta}{\pi \, r_1^2} \right)$$

where θ is the viewing angle with respect to the normal to the surface.

The nominal ocular hazard distance, r_{NOHD}, for a Lambertian source is obtained from the small source radiant exposure MPE as follows:

$$r_{NOHD} = \left(\frac{Q \cos \theta}{\pi \, H_{MPE,\,small\ src.}} \right)^{1/2}$$

The maximum radiant energy output of the laser obtained in the previous example is 0,42 J, and the specified viewing angle is $\theta = 0$ rad. Assuming that the target is also perfectly reflecting, the minimum safe viewing distance is

$$r_{NOHD} = \sqrt{\frac{0{,}42 \text{ J} \times \cos(0)}{\pi \times 0{,}05 \text{ J} \cdot \text{m}^{-2}}} = 1{,}6 \text{ m}$$

A.4 Maximum permissible exposure (MPE) – Repetitively pulsed systems

The rules applying to exposures from repetitively pulsed systems (or exposures from scanning laser systems) are set out in 13.3.

Example A.4-1

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

Solution:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Example A.4-2

Determine the intrabeam MPE for direct ocular exposure to the radiation from a Nd:YAG laser (λ = 1 060 nm) operating at a frequency of F = 20 Hz with a pulse width of t = 1 ms.

Solution:

As the laser does not operate in the visible part of the spectrum, protection is not afforded by the blink reflex. A reasonable estimate of a hazardous chance exposure time can be taken as 10 s. For this time period, the total number of pulses is:

$$\mathrm{N} = T \times F = 10\ \mathrm{s} \times 20\ \mathrm{Hz} = 200$$

Subclause 13.3 includes three criteria which must be considered, and the most restrictive one applies to this evaluation. The value of C_6 is 1 in these calculations since the beam is emitted from a small source. The value of C_7 from notes to tables 1 to 4 is also 1 for the 1 060 nm wavelength.

From 13.3a), the exposure from any single pulse shall not exceed the single pulse MPE. Thus the radiant exposure from table 6 for the time period of 1 ms is:

$$H_{\mathrm{single}} = 90\ t^{0,75}\ C_6\ C_7\ \ \mathrm{J{\cdot}m^{-2}} \qquad = 90 \times 0{,}001^{0,75} \times 1 \times 1\ \mathrm{J{\cdot}m^{-2}} = 0{,}506\ \mathrm{J{\cdot}m^{-2}}.$$

From 13.3b), the average exposure for a pulse train of exposure duration T shall not exceed the MPE for a single pulse of exposure duration T. For the 10 s duration (the total exposure time), table 6 limits the radiant exposure to:

$$H_{\mathrm{T}} = 90\ t^{0,75}\ C_6\ C_7\ \mathrm{J{\cdot}m^{-2}} = 90 \times 10^{0,75} \times 1 \times 1\ \mathrm{J{\cdot}m^{-2}} = 506\ \mathrm{J{\cdot}m^{-2}}$$

Since there are N = 200 pulses in the 10 s period, the average irradiance criteria results in a single pulse radiant exposure of:

$$H_{\mathrm{single.avg}} = \frac{H_{\mathrm{T}}}{\mathrm{N}} = \frac{506}{200}\,\mathrm{J \cdot m^{-2}} = 2{,}53\ \mathrm{J \cdot m^{-2}}$$

From 13.3c), the average exposure from pulses within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor C_5 (where $C_5 = N^{-1/4}$). For the N = 200 pulses in the 10 s period, the radiant exposure under this criteria would be:

$$H_{\mathrm{train}} = H_{\mathrm{single}} \times \mathrm{N}^{-0,25} = 0{,}506 \times (200)^{-0,25}\ \mathrm{J{\cdot}m^{-2}} = 0{,}135\ \mathrm{J{\cdot}m^{-2}}$$

Since the limit from the repetitive pulse criteria of 13.3 c) is the most restrictive, the single pulse MPE for this system would be 0,135 $\mathrm{J{\cdot}m^{-2}}$. The MPE could also be expressed in terms of irradiance as:

$$E_{\mathrm{MPE}} = \frac{H_{\mathrm{train}}}{t} = \frac{0{,}135\ \mathrm{J \cdot m^{-2}}}{10^{-3}\ \mathrm{s}} = 135\ \mathrm{W \cdot m^{-2}}$$

A.5 Nominal ocular hazard distance (NOHD)

The NOHD represents that range at which under ideal conditions, the irradiance and the radiant exposure fall below the appropriate MPE.

The irradiance at a distance *r* from a laser source is given by:

$$E = \frac{4\,P_o\,e^{-\mu r}}{\pi\,(a + r\phi)^2} \tag{1}$$

NOTE *a* and ϕ are measured at the 1/e points of the beam profile, when the beam profile is assumed to be Gaussian. In practice only gas lasers produce beams having Gaussian profiles, most solid state lasers having distinctly non-regular multi-mode beam structures, and in this latter case the following formula should be used:

$$L = \frac{I\,e^{-\mu r}}{r^2}$$

where I = radiant intensity ($W \cdot sr^{-1}$) (see 9.2 on measurements).

If I is not known and cannot be measured, the value for P_o in equation (1) above can be increased by 2,5 for laser systems known to have a multi-mode beam structure.

The term $e^{-\mu r}$ accounts for losses due to atmospheric attenuation and may be neglected for most purposes, simplifying equation (1) to:

$$E = \frac{4\,P_o}{\pi\,(a + r\phi)^2} \tag{2}$$

When E is replaced with E_{MPE}, r becomes the NOHD and the expression can be solved for NOHD:

$$\text{NOHD} = \frac{\sqrt{4P_o/\pi\,E_{MPE}} - a}{\phi} \tag{3}$$

If the effects of atmospheric attenuation are to be included, a simple solution to equation (1) in terms of *r*, cannot be found. However, the following approach will lead to an oversafe result:

$$r_\mu = 0{,}5\; r_c\; (1 + e^{-\mu r c}\;) \tag{4}$$

where

r_μ is the distance including atmospheric attenuation, and

r_c is the distance calculated from equation (3).

A reliable estimate for μ, the atmospheric attenuation coefficient, can be obtained from the following formula:

$$\mu = 10^{-3} \times \frac{3{,}91}{V} \times \left(\frac{0{,}55}{\lambda}\right)^{A}\; m^{-1} \tag{5}$$

where

$A = 0{,}585\; V^{\;0{,}33}$

V = visual range in km

λ = wavelength in µm ($0{,}4 < \lambda < 2$).

Use of optical viewing aids

Where viewing aids (telescopes, binoculars, etc.) are used to view a source of laser radiation, it is necessary to extend the NOHD to account for the increase in radiation entering the eye.

If the diameter of the exit pupil of the optical viewing aid is not greater than 7 mm, the increase in the amount of radiation entering the eye is dependent on the factor:

$$G = \frac{\text{diameter of objective lens or aperture of viewing aid}}{\text{theoretical pupillary diameter}} = \frac{D_o}{7 \times 10^{-3}}$$

The extended NOHD now becomes

$$\text{NOHD} = \text{basic NOHD} \times G + \frac{a(G-1)}{\phi}$$

in the worst case where the beam diameter is greater than the objective lens diameter, and when the exit pupil diameter is less than the eye pupil diameter.

Unless provided with special laser attenuating filters, no allowance should be made for transmission losses in viewing optics, as many devices have a high transmittance (0,8) extending well into the infra-red region of the spectrum above 2 000 nm.

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

Example A.5-1

A laser with a Gaussian beam profile has an output of 4 W, a beam divergence of 0,7 mrad and an exit beam diameter of 1 mm. If the appropriate MPE is 10 W·m^{-2} calculate the NOHD, assuming negligible atmospheric attenuation.

Solution:

Substituting in equation (3) gives:

$$\text{NOHD} = \frac{\sqrt{(4 \times 4)/10\,\pi} - 0{,}001}{0{,}7 \times 10^{-3}}\ \text{m} = \frac{0{,}7136 - 0{,}001}{0{,}7 \times 10^{-3}}\ \text{m} = 1{,}018\ \text{km}$$

Example A.5-2

Beam expanding optics are fitted to the laser in the previous example which reduces the beam divergence to 0,1 mrad and increases the beam diameter to 7 mm. Calculate the NOHD.

Solution:

The new NOHD is:

$$\text{NOHD} = \frac{\sqrt{(4 \times 4)/10\,\pi} - 7 \times 10^{-3}}{0{,}1 \times 10^{-3}}\ \text{m} = 7{,}07\ \text{km}$$

Note the importance of beam divergence in determining the NOHD. Also note that in this case, the beam exit diameter *a* can be neglected.

Example A.5-3

The laser in example A.5-2 operates at 550 nm. Calculate the modified NOHD, assuming a visual range of 20 km.

Solution:

The atmospheric attenuation coefficient, μ, is obtained using equation (5):

$$\mu = 10^{-3} \times \frac{3{,}91}{20} \times \left(\frac{0{,}55}{0{,}55}\right)^{A} = 1{,}95 \times 10^{-4}\ \mathrm{m}^{-1}$$

The modified NOHD can now be obtained from equation (4):

$$r_{\mu} = 0{,}5 \times 7{,}07\ (1 + e^{-(1{,}95 \times 10^{-4} \times 7{,}07 \times 10^{3})})\ \mathrm{m} = 4{,}4\ \mathrm{km}$$

NOTE An exact solution of equation (1) results in an NOHD of 4,3 km.

Example A.5-4

A surveying He-Ne laser (λ = 633 nm) of output power 3 mW emits a beam of initial diameter 13 mm, which expands to 18 mm at a distance of 50 m from the laser:

a) How long is it safe to view the laser directly from a distance of 60 m?

b) What is the minimum distance for safe direct viewing of this laser for a period of 3 min?

Solution:

a) The output power $P_o = 3 \times 10^{-3}$ W, and the initial beam diameter a = 0,013 m. The beam divergence is therefore

$$\phi = \frac{0{,}018 - 0{,}013}{50}\ \mathrm{rad} = 10^{-4}\ \mathrm{rad}$$

For an exposure duration between 10 s and 3×10^4 s, the appropriate MPE is given in table 6 as one of three possibilities depending on the exposure duration, t, relative to the break point, T_2, and for $t > T_2$ on the value of α:

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

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

which is equivalent to

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

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

$$E_{\mathrm{MPE}} = 10\ \mathrm{W \cdot m^{-2}}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

Example A.5-5

A hand-held infra-red laser surveying instrument has the following characteristics:

wavelength λ is 903 nm;

pulse repetition frequency *F* is 300 Hz;

peak power per pulse P_p is 30 W;

energy per pulse Q_p is 6 × 10^{-7} J;

beam divergence ϕ is 10 mrad;

effective exit aperture diameter (equivalent circular section beam) is 55 mm.

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

a) for viewing by the unaided eye, and

b) when using 8 × 50 binoculars.

Solution:

a) Unaided eye condition

There are three stages to this assessment for a pulsed laser source; the first two are on the basis of the pulses entering the eye, and the third is determined by the accumulative and averaged effects of a multi-pulse exposure.

In this example, it is assumed that the subtense α is less than α_{min} and for a small source C_6 = 1. If there is no intentional viewing, the exposure time to be used is 100 s; during this time the number of pulses is:

$$N = F \times t = 300 \text{ Hz} \times 100 \text{ s} = 3 \times 10^4$$

Single-pulse assessment

From the laser specification 700 nm < λ < 1 050 nm, the pulse width t_p is given by 30 W $\times$ t_p = 6 $\times$ 10^{-7} J, thus t_p = 20 ns.

Table 6 gives the single-pulse MPE for this radiation with the exposure time of 20 ns, as:

$$H_{MPE} = 5 \times 10^{-3}\ C_4\ C_6\ \text{J·m}^{-2}$$

where $C_4 = 10^{(903-700)/500}$ = 2,55 and C_6 = 1.

Multiple pulse assessment

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

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

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

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

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

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

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

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

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

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

Average exposure assessment

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

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

where C_4 = 2,55 and C_7 = 1.

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

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

The average power of the pulse train is:

$$P_{\text{avg}} = P_{\text{p}} \times t_{\text{p}} \times F = 30\ \text{W} \times 20 \times 10^{-9}\ \text{s} \times 300\ \text{Hz} = 1{,}8 \times 10^{-4}\ \text{W}$$

Therefore the limit for the distance is

$$r_{\text{NOHD}} = \frac{1}{\phi} \times \left(\sqrt{\frac{4\,P_{\text{avg}}}{\pi\,E_{\text{MPE,avg}}}} - a \right)$$

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

This result is negative. Thus, on the basis of the averaged exposure, the instrument is safe for viewing by the unaided eye at any distance. Therefore, for this instrument when only viewing by the unaided eye is involved, the appropriate NOHD is zero.

b) **Binocular viewing condition**

The pupil exit diameter of this instrument is 50/8 mm = 6,25 mm. Since this is less than 7 mm, it is assumed that all of this radiation enters the eye.

The increase in irradiance at the eye over that which exists at the instruments objective lens is given by:

$$G^2 = \left(\frac{D_{\text{o}}}{7 \times 10^{-3}} \right)^2 = \left(\frac{5{,}0 \times 10^{-2}\ \text{m}}{7 \times 10^{-3}\ \text{m}} \right)^2 = 51$$

where it is assumed that there is no attenuation through the optics.

Since the single-pulse assessment gives the most restricted condition for r in this case, the reduced single-pulse MPE ($E_{\text{MPE,train}}$) must be used to determine the NOHD. The maximum permitted irradiance at the objective lens is reduced by the factor G^{-2}:

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

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

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

It is consequently hazardous for this laser instrument to be viewed with binoculars at distances of less than 9,5 m.

This example serves to illustrate the wide hazards involved in using invisible radiation lasers in open areas. Because of the requirement for 50 mm diameter collecting optics in classification, the above mentioned laser product would be classified as Class 3B.

Example A.5-6

A neodymium-glass Q-switched laser rangefinder has the following characteristics:

wavelength = 1 060 nm;

peak power per pulse P_p = 1,5 MW;

energy per pulse Q_p = 45 mJ;

pulse repetition rate = 12 per minute;

exit aperture beam diameter = 10 mm;

beam divergence angle = 1 mrad.

What is the effective NOHD on the basis of the single-pulse threshold (a) for exposure of the unaided eye, and (b) when intrabeam viewing through 50 mm diameter optics is involved? (Effects of beam attenuation or refractive focusing due to atmospheric transmission are neglected in these calculations.)

Solution:

a) **Unaided eye condition**

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

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

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

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

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

Single-pulse assessment (condition 13.3a))

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

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

where C_6 = 1 and C_7 = 1, therefore

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

Average irradiance assessment (condition 13.3b))

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

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

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

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

Multiple-pulse assessment (condition 13.3c))

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

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

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

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

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

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

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

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

b) **Binocular viewing condition**

When 50 mm diameter collecting optics are involved in the intrabeam viewing of this laser, the NOHD is increased because the maximum permitted irradiance is reduced by the gain factor:

$$G^{-2} = \left(\frac{7\ \text{mm}}{50\ \text{mm}} \right)^2 = 1{,}96 \times 10^{-2}$$

The equation for the multiple-pulse assessment, modified by the insertion of the gain factor $1{,}96 \times 10^{-2}$, gives the following result for the NOHD:

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

Thus, in view of the very short pulse duration for this laser, while a telescopic system is used, even the briefest exposure of the eye to the laser radiation is hazardous at distances less than 13,18 km from the laser.

A.6 Accessible emission limits for diverging beam, small sources

Introduction:

Intrabeam viewing conditions exist whenever the conditions of extended source viewing are not met, i.e., whenever the apparent source (e.g. approximately the beam waist for beams with high divergence) forming the retinal image appears at an angle α not larger than the limiting angular subtense α_{min} when determined at the measurement distance (not less than 100 mm). Examples of such sources are laser beams (collimated or focused), beams through a small aperture, optical fibre ends, or the emitting surface of a semiconductor laser.

All of the examples in clause A.6 assume that the beam emerging from the small source is diverging (i.e., not collimated) and that the far-field beam profile is Gaussian. The Gaussian approximation simplifies calculations and works well as a conservative estimate for many divergent beam sources (e.g., optical fibre). In addition, all of the examples assume that intentional viewing is not inherent in the design or function of the sources described; therefore, the time base is 100 s (see 8.4 e)).

Diameter of a divergent beam

The diameter of a divergent beam, d_{63}, at a distance r from the apparent source is required to perform AEL and MPE calculations involving an aperture. Most manufactures of divergent beam sources will specify the divergence in terms of a numerical aperture or NA. The NA of a point source is defined as the sine of one-half the divergence, ϕ, of the output beam, as measured at the 5 %-of-peak-irradiance points. That is

$$\mathrm{NA} = \sin\frac{\phi}{2}$$

and

$$\frac{\phi}{2} = \arcsin(\mathrm{NA})$$

For a Gaussian beam, the beam diameter that corresponds to the 5 %-of-peak-irradiance points contains 95 % of the total power or energy. The beam diameter, d_{95}, at a distance r from the apparent source is given by:

$$d_{95} = a + 2\,r\,\tan\frac{\phi}{2} = a + 2\,r\,\tan\left(\arcsin(\mathrm{NA})\right)$$

Since a is of the order of a few tens of µm, it can be ignored in most situations. In addition, for safety calculations the beam diameter at the 63 % total power (or energy) points is used rather than the 95 % points. The conversion factor for a Gaussian beam is 1,7 (i.e., d_{95}/d_{63} = 1,7); hence, the beam diameter is approximated by:

$$d_{63} = \frac{d_{95}}{1{,}7} = \frac{2\,r}{1{,}7}\tan\left(\arcsin(\mathrm{NA})\right) = \frac{2\,r\,\mathrm{NA}}{1{,}7} \qquad (1)$$

A single-mode optical fibre is a special case of a point-type optical source. The divergence of a single-mode fibre is specified in terms of the fibre mode-field diameter, w_o, and the wavelength, λ, of the source. The beam diameter of a single-mode optical fibre, at a distance r, is approximated by:

$$d_{63} = \frac{2\sqrt{2}\,r\,\lambda}{\pi\,w_o} \qquad (2)$$

where the wavelength, λ, is expressed in the same units as the mode-field diameter, w_o.

Power passing through an aperture

Many of the classification procedures require the measurement of the power (or energy) passing through a specified aperture located at a specified distance from the apparent source. For a Gaussian beam, the fraction of the total power (or energy) passing through a circular aperture of diameter, d_a, at a distance r, can be expressed in terms of a coupling parameter

$$\eta = 1 - e^{-\left(\frac{d_a}{d_{63}}\right)^2} \tag{3}$$

where d_{63} is the beam diameter, determined at the 63 % points (i.e., 1/e points for a Gaussian beam) at the aperture distance. The total power (or energy) passing through the aperture is

$$P_a = \eta\, P_o \quad \text{or} \quad Q_a = \eta\, Q_o \tag{4}$$

where P_o is the total power (and Q_o is the total energy) emitted from the apparent source.

Example A.6-1

An optical-fibre transmitter emits at a wavelength of 850 nm from a 100 μm core diameter multi-mode fibre with a numerical aperture of 0,3. If the transmitter is operated in CW mode, what is the maximum total power allowed for classification as

a) Class 1, and

b) Class 1M.

Solution:

a) **Class 1**

The time base used for a Class 1 system is 100 s. Table 1 indicates that the AEL for emission in the wavelength range 700 nm to 1 050 nm with an exposure duration in the range from 10 s to 3 × 10⁴ s depends on the value of T_2 given in the notes to tables 1 to 4 by the expression:

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

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

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

where

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

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

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

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

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

b) **Class 1M**

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

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

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

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

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

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

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

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

Example A.6-2

An optical fibre transmitter emitting at 780 nm is used for digital data transmission at a rate of 125 Mbits/s. The transmission code used is a balanced code (i.e., equal numbers of one-bits and zero-bits in any group of two or three bytes long) and, therefore, the average power emitted is not data dependent. The numerical aperture of the product transmitter port has been determined to be within the range 0,16 to 0,18. Determine (a) Class 1, (b) Class 1M and (c) Class 3R power limits and determine which are applicable.

Solution:

Since the emission is modulated, the requirements in 8.4 for repetitively pulsed or modulated lasers must be considered. The high data rate (i.e., short pulse times) results in the most restrictive of the three requirements identified in 8.4 being requirement "b". In this situation, the emission is treated like a CW source with a power level equal to the average power emitted from the transmitter.

a) **Class 1**

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

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

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

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

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

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

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

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

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

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

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

b) **Class 1M**

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

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

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

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

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

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

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

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

c) **Class 3R**

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

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

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

Example A.6-3

An optical fibre transmitter emitting at 1 300 nm is used for digital data transmission at a rate of 630 Mbits/s. The transmission code used is a balanced code and, therefore, the average power emitted is not data dependent. The transmitter assembly is pigtailed to a single mode fibre having a mode field diameter of 10 µm.

a) Determine the maximum average output power for Class 1M and Class 3R AELs.

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

Solution:

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

a) **1 300 nm**

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

Class 1M

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

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

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

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

where C_4 = 5 and C_7 = 8 therefore

$$P_{AEL} = 15{,}6\ \mathrm{mW}$$

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

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

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

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

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

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

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

Class 3R

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

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

where C_4 = 5 and C_7 = 8, therefore

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

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

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

b) **1 550 nm**

Class 1M

If the same system is operated at 1 550 nm, then the procedure for performing the calculations is the same except that the AEL expression and apertures associated with the 1550 nm wavelength are used.

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

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

The beam diameter at 100 mm is

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

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

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

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

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

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

Annex B
(informative)

Biophysical considerations

B.1 Anatomy of the eye

See figure B.1.

Figure B.1(A)

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

Figure B.1(B)

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

Figure B.1(C)

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

Figure B.1(D)

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

Figure B.1(E)

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

B.2 The effects of laser radiation on biological tissue

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

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

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

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

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

Non-linear effects. Short-pulsed high peak-power (i.e., Q-switched or mode-locked) lasers may give rise to tissue damage with a different combination of induction mechanisms. Energy is delivered to the biological target in a very short time and hence a high irradiance is produced. The target tissues experience such a rapid rise in temperature, that the liquid components of their cells are converted to gas. In most cases, these phase changes are so rapid that they are explosive and the cells rupture. The pressure transients may result from thermal expansion and both may also result in shearing damage to tissues remote from the absorbing layers by bulk physical displacement. At sub-nanosecond exposures, self-focusing of the ocular media further concentrates laser energy from a collimated beam and further lowers the threshold between approximately 10 ps and 1 ns. Furthermore, other non-linear optical mechanisms appear to play a role in retinal injury in the sub-nanosecond region.

All of the above-described damage mechanisms have been shown to operate in the retina, and are reflected in the breakpoints or changes of slope in the safe exposure levels described in this standard.

Table B.1 – Summary of pathological effects associated with excessive exposure to light

<table>
<tr><th>CIE Spectral region [a]</th><th>Eye</th><th colspan="2">Skin</th></tr>
<tr><td>Ultra-violet C
(180 nm to 280 nm)</td><td rowspan="2">Photokeratitis</td><td rowspan="2">Erythema (sunburn)
Accelerated skin ageing process
Increased pigmentation</td><td rowspan="2"></td></tr>
<tr><td>Ultra-violet B
(280 nm to 315 nm)</td></tr>
<tr><td>Ultra-violet A
(315 nm to 400 nm)</td><td>Photochemical cataract</td><td rowspan="2">Pigment darkening
Photosensitive reactions</td><td rowspan="5">Skin burn</td></tr>
<tr><td>Visible
(400 nm to 780 nm)</td><td>Photochemical and thermal retinal injury</td></tr>
<tr><td>Infra-red A
(780 nm to 1 400 nm)</td><td>Cataract, retinal burn</td><td rowspan="3"></td></tr>
<tr><td>Infra-red B
(1,4 µm to 3,0 µm)</td><td>Aqueous flare, cataract, corneal burn</td></tr>
<tr><td>Infra-red C
(3,0 µm to 1 mm)</td><td>Corneal burn only</td></tr>
<tr><td colspan="4">[a] The spectral regions defined by the CIE are short-hand notations useful in describing biological effects and may not agree perfectly with spectral breakpoints in the MPE tables.</td></tr>
</table>

B.2.1 Hazards to the eye

A brief description of the anatomy of the eye is given in clause B.1. The eye is specially adapted to receive and transduce optical radiation. The absorption properties of the eye with respect to radiations of different wavelengths are shown in figure B.2 and the associated pathologies caused by excessive exposures are summarized in table B.1. Thus, lasers emitting ultra-violet and far infra-red radiation represent a corneal hazard while systems emitting visible and near infra-red wavelengths will be transmitted to the retina.

Visible and near infra-red lasers are a special hazard to the eye because the very properties necessary for the eye to be an effective transducer of light result in high radiant exposure being presented to highly pigmented tissues. The increase in irradiance from the cornea to the retina is approximately the ratio of the pupil area to that of the retinal image. This increase arises because the light which has entered the pupil is focused to a "point" on the retina. The pupil is a variable aperture but the diameter may be as large as 7 mm when maximally dilated in the young eye. The retinal image corresponding to such a pupil may be between 10 µm and 20 µm in diameter. With intra-ocular scattering and corneal aberrations considered, the increase in irradiance between the cornea and the retina is of the order of 2×10^5.

If an increase of 2×10^5 is assumed, a 50 $W \cdot m^{-2}$ beam on the cornea becomes 1×10^7 $W \cdot m^{-2}$ on the retina. In this standard, a 7 mm pupil is considered as a limiting aperture as this is a worst-case condition and is derived from figures obtained from the young eye where pupillary diameters of this order have been measured. An exception to the assumption of a 7 mm pupil was applied in the derivation of exposure limits to protect against photoretinitis whilst viewing bright visible (400 nm to 700 nm) laser sources for periods in excess of 10 s. In this latter situation, a 3 mm pupil was assumed as a worst-case condition; however, a 7 mm irradiance averaging aperture for measurement was still considered appropriate due to physiological movements of the pupil in space. Hence, AELs for durations greater than 10 s are still derived for a 7 mm aperture.

If an intense beam of laser light is brought to a focus on the retina only a small fraction of the light (up to 5 %) will be absorbed by the visual pigments in the rods and cones. Most of the light will be absorbed by the pigment called melanin contained in the pigment epithelium. (In the macular region some energy in the 400 nm to 500 nm range will be absorbed by the yellow macular pigment.) The absorbed energy will cause local heating and will burn both the pigment epithelium and the adjacent light sensitive rods and cones. This burn or lesion may result in a loss of vision. Photochemical injuries, although non-thermal, are also localized in the pigment epithelium.

Depending on the magnitude of the exposure, such a loss of vision may or may not be permanent. A visual decrement will usually be noted subjectively by an exposed individual only when the central or foveal region of the macula is involved. The fovea, the pit in the centre of the macula, is the most important part of the retina as it is responsible for sharpest vision. It is the portion of the retina that is used "to look right at something". This visual angle subtended by the fovea is approximately equal to that subtended by the moon. If this region is damaged, the decrement may appear initially as a blurred white spot obscuring the central area of vision; however, within two or more weeks, it may change to a black spot. Ultimately, the victim may cease to be aware of this blind spot (scotoma) during normal vision. However, it can be revealed immediately on looking at an empty visual scene such as a blank sheet of white paper. Peripheral lesions will only be registered subjectively when gross retinal damage has occurred. Small peripheral lesions will pass unnoticed and may not even be detected during a systematic eye examination.

In the wavelength range from 400 nm to 1 400 nm, the greatest hazard is retinal damage. The cornea, aqueous humour, lens and vitreous humor are transparent for radiation of these wavelengths. In the case of a well-collimated beam, the hazard is virtually independent of the distance between the source of radiation and the eye, because the retinal image is assumed to be a diffraction-limited spot of around 10 μm to 20 μm diameter. In this case, assuming thermal equilibrium, the retinal zone of hazard is determined by the limiting angular subtense α_{min}, which generally corresponds to retinal spot of approximately 25 μm in diameter.

In the case of an extended source, the hazard varies with the viewing distance between the source and the eye, because whilst the instantaneous retinal irradiance only depends on the source's radiance and on the lens characteristics of the eye, thermal diffusion of energy from larger retinal images is less efficient, leading to a retinal spot-size dependence for thermal injury which does not exist for photochemical injury (dominating only in the 400 nm to 600 nm spectral region). In addition, eye movements further spread the absorbed energy for CW laser exposures, leading to different dependencies of risk for differing retinal image sizes.

In the derivation of limits for ocular exposure in the retinal hazard region, correction factors for eye movements were only applied for viewing durations exceeding 10 s. Although physiological eye movements known as saccades do spread the absorbed energy in minimal retinal images (of the order of 25 μm or less) within the 0,1 s to 10 s time regime, the limits provide a desired added safety factor for this viewing condition. At 0,25 s, the mean retinal spot illuminated is approximately 50 μm. By 10 s, the illuminated retinal zone becomes approximately 75 μm and the added safety factor for the minimal image condition becomes 1,7 over a stabilized eye, with the spot-size dependence taken into account. By 100 s, it is rare to achieve an illuminated zone (measured at 50 % points) as small as 135 μm leading to an additional safety factor of 2-3 or more for the minimal image condition.

The data from eye-movement studies and retinal thermal injury studies were combined to derive a break-point in viewing time T_2 at which eye movements compensated for the increased theoretical risk of thermal injury for increased retinal exposure durations if the eye were immobilized. Because the thermal injury threshold expressed as radiant power entering the eye decreases as the exposure duration t raised to the –0,25 power (i.e. a reduction of only 44 % per tenfold increase in duration), only moderate increases in the exposed retinal area will compensate for the increased risk for longer viewing times. The ever-increasing retinal area of irradiation resulting from greater eye movements with increased viewing time takes longer to compensate for the reduced impact of thermal diffusion in larger extended sources. Thus, for increasing angular subtense α, the break-point T_2 increases from 10 s for small sources to 100 s for larger sources. Beyond 100 s there is no further increase in risk of thermal injury for small and intermediate size images. The specification of limits and measuring conditions attempt to follow these variables with some simplification leading to a conservative determination of risk. It is conservatively assumed that retinal thermal injury thresholds vary inversely with retinal image size (stabilized) between approximately 25 µm to 1 mm (corresponding to angular sizes of 1 µm to 59 mrad), whilst beyond 1,7 mm (corresponding to angular sizes greater than 100 mrad), there is no spot-sized dependence.

For photochemically induced retinal injury there is no spot size dependence for a stabilized image. Unlike thermal injury mechanism, the thresholds for photochemical injury are highly wavelength dependent and are exposure dose dependent, i.e. the thresholds decrease inversely with the lengthening of exposure time. Studies of photochemical retinal injury from welding arcs subtending angles of the order of 1 mrad to 1,5 mrad showed typical lesion sizes of the order of 185 µm to 200 µm (corresponding to visual angles of 11 mrad to 12 mrad), clearly showing the influence of eye movements during fixation; these and other studies of eye movements during fixation led to the derivation of MPEs to protect against photochemical retinal injury. These studies also led to MPE irradiance to be specified as being averaged over 11 mrad for exposure durations between 10 s and 100 s. Hence, sources with an angular subtense α less than 11 mrad were treated equally with "point-type" sources, and the concept of α_{min} was extended to CW laser viewing. This approach was not strictly correct, as an irradiance measurement of an 11-mrad source is not equivalent to irradiance averaging over a field of view (γ) of 11 mrad unless the source had a rectangular ("top-hat") radiance distribution. Hence, in this edition of the standard, distinction is made between angular subtense of a source and irradiance averaging for photochemical MPE values. For viewing times in excess of approximately 30 s to 60 s, the saccadic eye motion during fixation is generally overtaken by behavioural movements determined by visual task, and it is quite unreasonable to assume that a light source would be imaged solely in the fovea for durations longer than 100 s. For this reason, the angle of acceptance γ_p is increased linearly with the square-root of t. The minimal angular subtense α_{min} correctly remains at the reference angle of 1,5 mrad for all exposure durations used in thermal retinal hazard evaluation. However, for photochemical retinal hazard assessment, the concept is actually different, as the angle γ_p is a linear angle of acceptance for the measurement of irradiance, and this is important to apply only for extended sources greater than approximately 11 mrad.

Viewing distance. In the case of a "point-type", diverging-beam source, the hazard increases with decreasing distance between the beam waist and the eye. The reason is that, with decreasing distance, the collected power increases, while the size of the retinal image can be assumed to remain nearly diffraction-limited for true laser sources down to a distance as close as 100 mm (due to the accommodation capabilities of the eye). The greatest hazard occurs at the shortest accommodation distance. With further reduced distance, the hazard to the unaided eye is also reduced, as there is a rapid growth of the retinal image and a corresponding reduction of the irradiance, even though more power may be collected. To simulate the risk of optically aided viewing of a collimated beam with binoculars or a telescope, the closest distance of approach of 2 m with a 50-mm aperture was assumed based upon the closest distance for clear viewing.

For the purpose of this standard, the shortest accommodation distance of the human eye is set to 100 mm at all wavelengths from 400 nm to 1 400 nm. This was chosen as a compromise, because all but a few young people and very few myopics cannot accommodate their eyes to distances of less than 100 mm. This distance may be used for the measurement of irradiance in the case of intrabeam viewing (see 8.2).

For wavelengths of less than 400 nm or more than 1 400 nm, the greatest hazard is damage to the lens or the cornea. Depending on the wavelength, optical radiation is absorbed preferentially or exclusively by the cornea or the lens (see table B.1). For diverging-beam sources (extended or point-type) of these wavelengths, short distances between the source and the eye should be avoided.

In the wavelength range from 1 500 nm to 2 600 nm, radiation penetrates into the aqueous humour. The heating effect is therefore dissipated over a greater volume of the eye, and the MPEs are increased for exposures less than 10 s. The greatest increase in the MPEs occurs for very short pulse durations and within the wavelength range of 1 500 nm to 1 800 nm where the absorbing volume is greatest. At times greater than 10 s, heat conduction redistributes the thermal energy so that the impact of the penetration depth is no longer significant.

B.2.2 Skin hazards

In general terms, the skin can tolerate a great deal more exposure to laser beam energy than can the eye. The biological effect of irradiation of skin by lasers operating in the visible (400 nm to 700 nm) and infra-red (greater than 700 nm) spectral regions may vary from a mild erythema to severe blisters. An ashen charring is prevalent in tissues of high surface absorption following exposure to very short-pulsed, high-peak power lasers. This may not be followed by erythema.

The pigmentation, ulceration, and scarring of the skin and damage of underlying organs may occur from extremely high irradiance. Latent or cumulative effects of laser radiation have not been found prevalent. However, some limited research has suggested that under special conditions, small regions of human tissue may be sensitized by repeating local exposures with the result that the exposure level for minimal reaction is changed and the reactions in the tissues are more severe for such low-level exposure.

In the wavelength range 1 500 nm to 2 600 nm, biological threshold studies indicate that the risk of skin injury follows a similar pattern to that of the eye. For exposures up to 10 s, the MPE is increased within this spectral range.

B.3 MPEs and irradiance averaging

In this standard, the maximum permissible exposure (MPE) values recommended by the ICNIRP have been adopted. The irradiance-averaging apertures (measurement apertures) recommended by the ICNIRP were adopted, or an additional safety factor applied by IEC TC76. The determination and derivation of the AELs, although generally based upon the MPEs, necessitated a risk analysis and determination of reasonably foreseeable exposure conditions. The choice of measurement aperture played a role in the derivation of AELs and reflects both biophysical and physiological factors. In some cases, considerations of risk assessment and simplification of expression played a role. Table B.2 provides a summary of the factors assumed in the choice of measurement apertures. In general, the recommendations of the ICNIRP were followed, or added safety factors applied.

B.4 Reference documents

1 International Commission on Non-Ionizing Radiation Protection (ICNIRP): Guidelines on limits of exposure to laser radiation of wavelengths between 180 nm and 1,000 µm. *Health Phys.* 71(5): 804-819, 1996.

2 International Commission on Non-Ionizing Radiation Protection (ICNIRP): Revision of guidelines on limits of exposure to laser radiation of wavelengths between 400 nm and 1,4 µm. *Health Phys.* 79(4):431-440.

3 Ness, J., Zwick, H.A., Stuck, B.A., Lund, D.J., Molchany, J.A. and Sliney, D.H.: Retinal image motion during deliberate fixation: implications to laser safety for long duration viewing. *Health Phys.* 78(2):131-142.

4 Roach, W.P., Johnson, P.E. and Rockwell, B.A.: Proposed maximum permissible exposure limits for ultrashort laser pulses, *Health Phys.* 76(4):349-354.

5 Sliney, D.H. and Wolbarsht, M.L.: *Safety with Lasers and Other Optical Sources,* New York, Plenum Publishing Corp., 1980.

6 United Nations Environment Programme (UNEP); World Health Organization (WHO); International Radiation Protection Association (IRPA): *Environmental Health Criteria No. 23: Lasers and Optical Radiation*, Geneva, WHO, 1982.

Table B.2 – Explanation of measurement apertures applied to the MPEs

Spectral band λ	Exposure time t	Aperture diameter	Comments and rationale for aperture diameter
180 nm to 400 nm	$t < 3 \cdot 10^4$ s	1 mm	Scatter in corneal epithelium and in stratum corneum leads to 1 mm; assumption of no movement of exposed tissue for continuous exposure conditions is applied by IEC. However, ICNIRP recommends 3,5 mm for lengthy exposures due to eye movements
400 nm to 600 nm photochemical	$t > 10$ s	3 mm in derivation of MPE, but 7 mm used for measurements	Lateral motion of 3-mm diameter pupil in space to produce 7-mm aperture averaging for CW exposures applicable for photochemical injury mechanism
400 nm to 1 400 nm thermal	All times t	7 mm	Diameter of dilated pupil and lateral motion in CW exposures
$\lambda > 1\,400$ nm	$t < 0{,}35$ s	1 mm	Thermal diffusion in stratum corneum and epithelial tissues
$\lambda > 1\,400$ nm	$0{,}35 \text{ s} < t < 10$ s $t > 10$ s	$1{,}5 \cdot t^{3/8}$ mm 3,5 mm	Greater thermal diffusion and movement of target tissue relative to beam after 0,35 s
$10^5 \le \lambda \le 10^6$ nm	All t	11 mm	Aperture to be greater than diffraction limit (i.e., approximately 10×) for accurate measurements

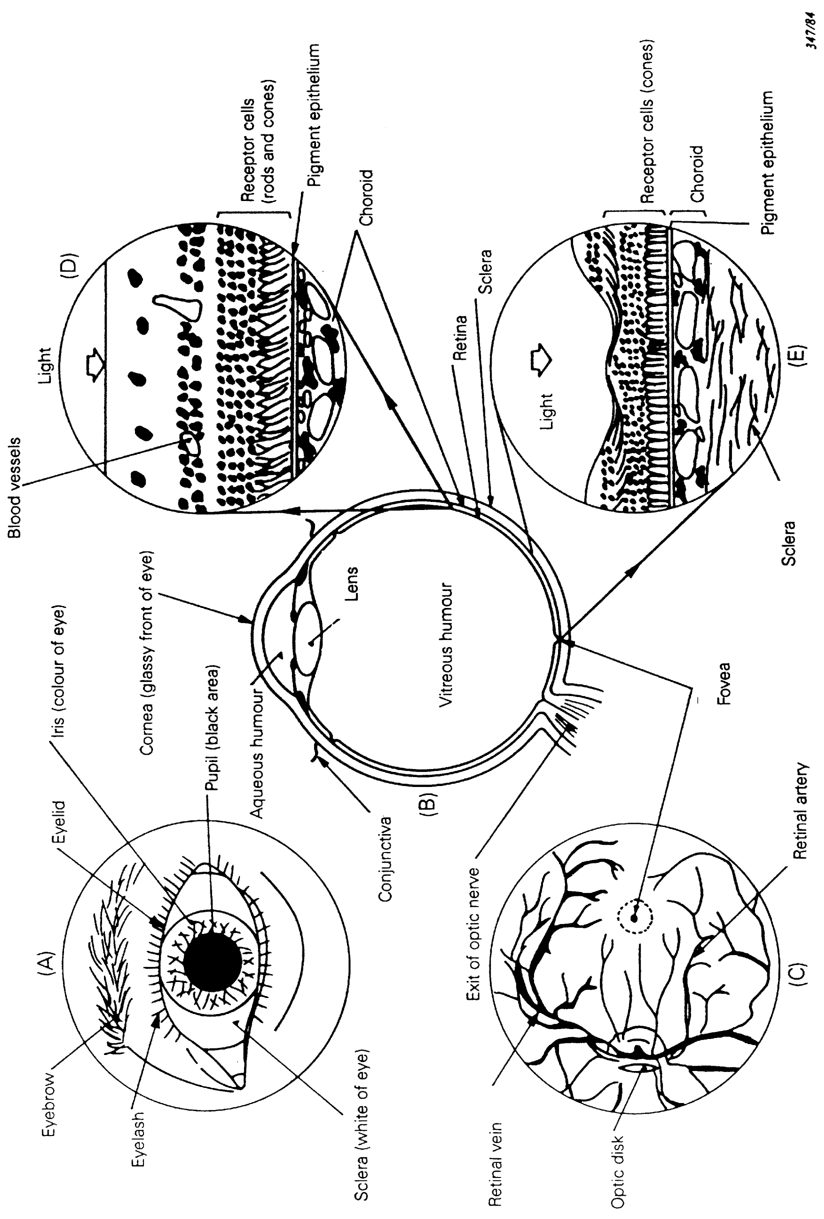
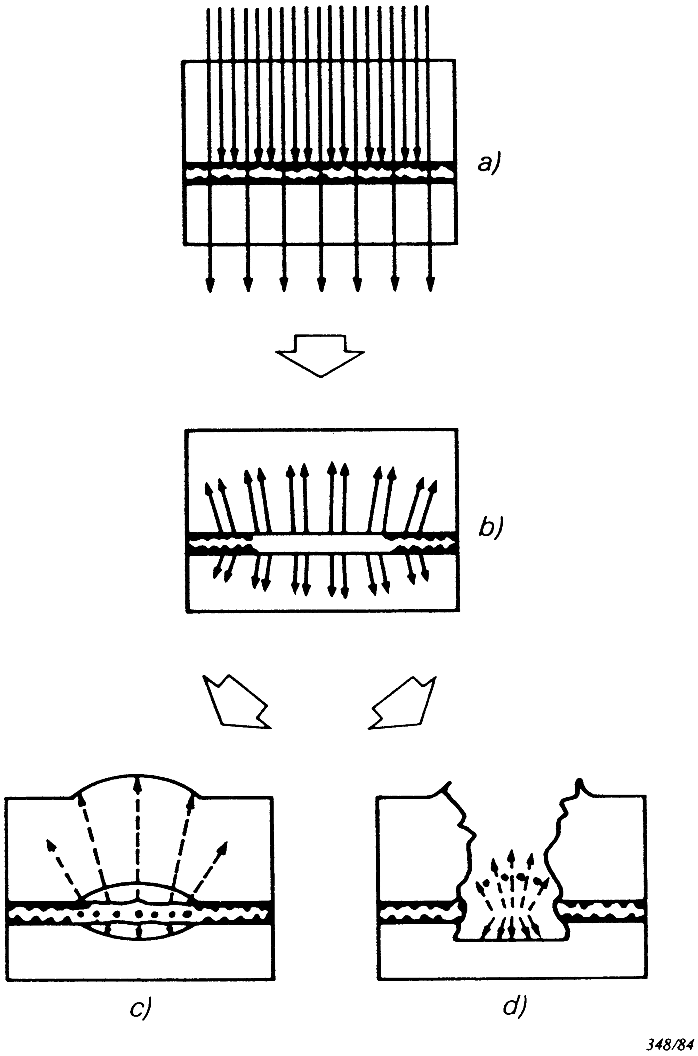


Figure B.1 – Anatomy of the eye



a) Laser energy is absorbed by the system.

b) The absorbed energy produces heat which is conducted to surrounding tissues.

c) In long-pulse or CW lasers the persistence of the thermal front gives rise to a progressively enlarging lesion.

d) In short-pulse lasers the high power density gives rise to explosive rupture of cells and damage by physical displacement.

Figure B.2 – Diagram of laser-induced damage in biological systems

Annex C
(informative)

Bibliography

Essentials of Lasers	L. Allen (Pergamon Press)
Lasers in Industry	S.S. Charschan (Van Nostrand Reinhold) New York, 1972
Introduction to laser Physics	B.A. Lengyel (J. Wiley)
Laser Physics	A. Maitland and M.H. Dunn (North Holland Publishing Co.)
Fundamentals of Optics	F.A. Jenkins and M.E. White (McGraw-Hill), 1950
Geometrical and Physical Optics	R.S. Longhurst (Longman)
Lasers and Light	Readings from Scientific American (W.H. Freeman and Col., 1969)
Laser Applications in Medicine and Biology, Volumes I, II and III	M.L. Wolbarsht (Plenum Press) New York, 1971, 1974, 1977
Third Conference on the Laser	L. Goldman, Editor (New York Academy of Sciences) Annals of the NY Academy of Sciences, Vol. 267, 1976
Lasers in Medicine	L. Goldman and R.J. Rockwell (Gordon and Breich), New York, 1971
Safety with Lasers and Other Optical Sources	D. Sliney and M. Wolbarsht (Plenum Press) New York, 1980
Introduction aux lasers	D.C. O'Shea, traduit par/translated by A. Blanc (Eyrolles) Paris, 1980
Les lasers	F. Chabannes (E.N.S.T.A.) Paris, 1980
Les lasers et leurs applications	A. Orszag-E. Hepner (Masson) Paris, 1980
Les lasers en ophtalmologie	H. Haut, S. Limon, M. Massin, G. Perdiel, Société française d'ophtalmologie (Masson) Paris, 1981
Biological Bases for and Other Aspects of a Performance Standard for Laser Products	F.A. Andersen, USDHHS Publication (FDA) 80-8092, October 1969

Annex D
(informative)

Summary tables

Table D.1 – Summary of the physical quantities used in this part 1

This table summarizes the physical quantities referred to in this part 1, and gives the unit (and the symbol for the unit) used for each of them. The definitions of the SI base units are taken from ISO 1000. The units and symbols are taken from IEC 60027-1.

Quantity	Name of unit	Unit symbol	Definition
Length	metre	m	The metre is the length of the path travelled by light in vacuum during a time interval of 1/229 792 458 of a second
	millimetre	mm	10^{-3} m
	micrometre	μm	10^{-6} m
	nanometre	nm	10^{-9} m
Area	square metre	m^2	1 m^2
Mass	kilogram	kg	The mass equal to the mass of the international prototype of the kilogram
Time	second	s	The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state caesium-133 atom
Frequency	hertz	Hz	The frequency of a periodic phenomenon equal to one cycle per second
Plane angle	radian	rad	The plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius
	milliradian	mrad	10^{-3} rad
Solid angle	steradian	sr	The solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere
Force	newton	N	1 $m \cdot kg \cdot s^{-2}$
Energy	joule	J	1 $N \cdot m$
Radiant exposure	joule per square metre	$J \cdot m^{-2}$	1 $J \cdot m^{-2}$
Integrated radiance	joule per square metre per steradian	$J \cdot m^{-2} \cdot sr^{-1}$	1 $J \cdot m^{-2} \cdot sr^{-1}$
Power	watt	W	1 $J \cdot s^{-1}$
	milliwatt	mW	10^{-3} W
Irradiance	watt per square metre	$W \cdot m^{-2}$	1 $W \cdot m^{-2}$
Radiance	watt per square metre per steradian	$W \cdot m^{-2} \cdot sr^{-1}$	1 $W \cdot m^{-2} \cdot sr^{-1}$
NOTE For convenience, multiples and submultiples of units have been included where appropriate.			

Table D.2 – Summary of manufacturer's requirements

Requirements subclause	Classification						
	Class 1	Class 1M	Class 2	Class 2M	Class 3R	Class 3B	Class 4
Description of hazard class 8.2	Safe under reasonably foreseeable conditions	As for Class 1 except may be hazardous if user employs optics	Low power; eye protection normally afforded by aversion responses	As for Class 2 except may be more hazardous if user employs optics	Direct intrabeam viewing may be hazardous	Direct intrabeam viewing normally hazardous	High power; diffuse reflections may be hazardous
Protective housing 4.2		Required for each laser product; limits access necessary for performance of functions of the products					
Safety interlock in protective housing 4.3	Designed to prevent removal of the panel until accessible emission values are below that for Class 3R				Designed to prevent removal of the panel until accessible emission values are below that for Class 3B		
Remote control 4.4	Not required					Permits easy addition of external interlock in laser installation	
Key control 4.5	Not required					Laser inoperative when key is removed	
Emission warning device 4.6	Not required				Gives audible or visible warning when laser is switched on or if capacitor bank of pulsed laser is being charged. For Class 3R only, applies if invisible radiation is emitted		
Attenuator 4.7	Not required					Gives means besides the On/Off switch to temporarily block beam	
Location controls 4.8	Not required				Controls so located that there is no danger of exposure to AEL above Classes 1 or 2 when adjustments are made		
Viewing optics 4.9	Not required	Emission from all viewing systems must be below Class 1M AEL					
Scanning 4.10	Scan failure shall not cause product to exceed its classification						
Class label 5.1 to 5.6	Required wording		Figures 14 and 15 and required wording				
Aperture label 5.7	Not required				Specified wording required		
Service entry label 5.9.1	Required as appropriate to the class of accessible radiation						
Override interlock label 5.9.2	Required under certain conditions as appropriate to the class of laser used						
Wavelength range label 5.10 & 5.11	Required for certain wavelength ranges						
LED label 5.12	Make required word substitutions for LED products						
User information 6.1	Operation manuals must contain instructions for safe use. Additional requirements apply for Class 1M and Class 2M						
Purchasing and service information 6.2	Promotion brochures must specify product classification; service manuals must contain safety information						
Medical products 7.1	For the safety of medical laser products, IEC 60601-2-22 applies						
NOTE This table is intended to provide a convenient summary of requirements. See text of this standard for complete requirements.							

Table D.3 – Summary of user precautions

Requirements subclause	Classification						
	Class 1	Class 1M	Class 2	Class 2M	Class 3R	Class 3B	Class 4
Laser safety officer 10.1	Not required but recommended for applications that involve direct viewing of the laser beam				Not required for visible emission Required for non-visible emission	Required	
Remote interlock 10.2	Not required					Connect to room or door circuits	
Key control 10.3	Not required					Remove key when not in use	
Beam attenuator 10.4	Not required					When in use prevents inadvertent exposure	
Emission indicator device	Not required				Indicates laser is energized for non-visible wavelengths	Indicates laser is energized	
Warning signs 10.5	Not required					Follow precautions on warning signs	
Beam path 10.6	Not required	Class 1M[a] as for Class 3B	Not required	Class 2M[b] as for Class 3B	Terminate beam at end of useful length		
Specular reflection 10.7	No requirements	Class 1M[a] as for Class 3B	No requirements	Class 2M[b] as for Class 3B	Prevent unintentional reflections		
Eye protection 10.8	No requirements					Required if engineering and administrative procedures not practicable and MPE exceeded	
Protective clothing 10.9	No requirements					Sometimes required	Specific requirements
Training 10.10	No requirements	Class 1M[a] as for Class 3R	No requirements	Class 2M[b] as for Class 3R	Required for all operator and maintenance personnel		

[a] Class 1M laser products that failed condition 1 of table 10. Not required for Class 1M laser products that failed condition 2 of table 10.

[b] Class 2M laser products that failed condition 1 of table 10. Not required for Class 2M laser products that failed condition 2 of table 10.

NOTE This table is intended to provide a convenient summary of precautions. See text of this standard for complete precautions.

Annex E
(informative)

High power laser considerations particularly appropriate to materials-processing laser products

E.1 General considerations

High power laser radiation has the potential ability to change by heating the shape, reflectivity, transmission or refractive index of optical components it passes through or is reflected from. This in turn can distort, reflect and/or deflect the laser radiation, and may permanently damage the optical component. Furthermore, sufficiently high power radiation has the ability to penetrate the wall of a protective housing by melting or vapourizing the material of its construction. The threshold for these effects depends on laser wavelength, peak power, exposure time and the thermomechanical and optical properties of the material irradiated. Environmental factors, especially airborne dust, can enhance the absorption of laser radiation. In principle, any Class 4 laser is capable of producing such effects.

Some of the effects encountered in the safety context are:

i) High power laser radiation melting, vapourizing, ablating, or in some other way penetrating a protective housing and/or producing toxic fumes.

ii) Significant energy absorption from a high power laser beam by a reflective or transmissive beam forming component, giving rise to changes in the properties of the reflected or transmitted beam (and consequently the generation of an errant beam) by virtue of:

   a) deformation of the component;

   b) induced changes in the bulk refractive index and absorption coefficient of the component.

   Thermal lensing is an effect caused by a) and/or b);

   c) induced changes in the surface absorption and/or reflectivity of the component. Multi-layer dielectric coatings are particularly prone to laser damage;

   d) catastrophic failure, i.e. penetration (burn through) of an opaque component (e.g. a mirror) or cracking of a transmissive component (e.g. a lens).

iii) Non-linear effects such as frequency doubling and stimulated Brillouin scattering.

E.2 Errant laser radiation

E.2.1 Errant radiation produced in normal operation of the laser product includes secondary reflections from beam line components. However, within the constraints of normal operation, service, and maintenance operations, certain fault conditions may arise in which relatively strong errant beams could be produced. These include:

– damage to beam path components by laser radiation, the environment or by mechanical impact;

– misalignment or displacement of a beam path component (for example, due to vibration, or failure of an automatic positioning device or a control software failure);

– penetration of a workpiece by laser radiation during processing or anomalous (strong or refocused) workpiece reflection;

– (following servicing) misalignment of a beam path component or the failure to replace a beam path component or a radiation barrier.

E.2.2 It is not always practical or desirable to build a protective housing capable of preventing human access to errant laser radiation under all the above conditions, but there is much that can be done by way of engineering design to limit or prevent some of the conditions outlined in E.2.1 from arising.

Measures include:

– controlling the environment in which beam path components are located (in particular, preventing particulate matter and/or condensation from collecting on laser irradiated surfaces of beam path components);

– securely mounting beam path components with minimum mechanical distortion of optical surfaces and adequate isolation from thermally and mechanically induced stresses;

– limiting unnecessary freedom of movement of component holders;

– installing mechanical stops or limit switches as a back up to prevent collisions between components in relative motion within the protective housing;

– fixing beam path components, their holders, and any screening within the protective housing so that tools are required for their removal;

– installing interlocking to ensure the presence of beam path components before operation (especially components which are mechanically controlled, for example, for beam switching);

– monitoring the overall transmission of laser power or deviations from the defined laser beam path;

– monitoring some aspect of the laser processing, for example optical emission;

– mechanically restricting access to the region of laser processing (for example, excluding foreign objects by means of a shroud).

E.2.3 In addition to the above engineering features, instructions may be needed to limit the intended use of the product, for example, to prevent the processing of a workpiece of such a material or surface curvature as would greatly increase the intensity of specular reflections or produce focusing of such radiation. For example, use may be limited to materials with unpolished, plain surfaces. Any limitations would need to be clearly defined in the information for the user and the product marked up accordingly.

E.3 Design of protective housings

E.3.1 Protective housings may be made up of passive guards and/or active guards to contain errant laser radiation. Passive guards rely on the intrinsic ability of their material of construction to resist penetration by laser radiation. Active guards make use of sensors or other devices to limit the time for which hazardous levels of errant radiation can persist within the protective housing. Active protection does not include real time human monitoring or manual shut-down of the laser.

E.3.2 Passive guards

In welding, cutting and drilling laser products, relatively thin walled, uncooled housing walls can provide adequate passive protection from errant radiation in normal operation, and under fault conditions arising beyond the laser focusing optics by virtue of the fact that such radiation is highly divergent.

The passive protection afforded by a protective housing can be enhanced by a local enclosure (e.g. a tube surrounding the laser beam, or a shroud surrounding the region of the workpiece undergoing processing), and by the strategic positioning of beam stops (e.g. below the workpiece, and behind beam turning mirrors). Where local enclosure is used, its presence during operation should be ensured either by interlocking or by securing it in position such that tools are required for its removal. Any part of a solid workpiece surface not on the defined beam path may be considered as contributing to beam enclosure within the protective housing if its presence can be ensured during operation (e.g. by use of a proximity sensor).

E.3.3 Active guards

An active guard must be capable of containing errant laser radiation incident on its surface for a time which safely exceeds the maximum time take for electronic (or other) means of detection of such errant laser radiation and laser source shut-down. This may involve, for example:

– a detector which forms an intrinsic part of the guard and relies on partial penetration of the housing for its operation (e.g. a monitor of the excess pressure of a fluid trapped within a double skinned wall);

– a detector which senses errant laser radiation on the guard directly, or by some secondary effect, such as a temperature rise.

E.4 Beam stop

Beam stops should be designed so that they operate in a fail-safe manner and, by engineering design, prevent full penetration at maximum laser power. The latter may be achieved by the use of low volatility/high thermal conductivity materials of construction, a large absorbing surface area, and/or by the incorporation of thermal sensors interlocked with the safety system.

E.5 Other conditions

E.5.1 Due regard should be given to the effect of the laser radiation generated by a laser product on the integrity of its protective housing and on the continuity of all signals or utilities relating to the safety of the laser product (e.g. electric or pneumatic supply cables operating automated workhandling equipment inside a protective housing), and to the associated hazards, including fire and fumes, caused by the laser exposure of these components.

E.5.2 Due regard should be given to the associated hazards from gases (for example, oxygen) used to assist laser-target interactions and from any fumes that are produced. These hazards include explosions, fires, toxic effects and oxygen depletion.

Annex F
(informative)

Related IEC Standards

This annex lists the other IEC documents related to mechanical and electrical safety that may incorporate lasers or LEDs and be associated with this part 1.

Note: When the international publication has been modified by CENELEC common modifications, the relevant EN/HD applies.

EN 41003:1993, *Particular safety requirements for equipment to be connected to telecommunication networks*

IEC 60065:1998, *Audio, video and similar apparatus – Safety requirements*

Note: Harmonized as EN 60065:1993 (modified)

IEC 60204-1:1992, *Electrical equipment of industrial machines – Part 1: General requirements*
Amendment 1, 1999

Note: Harmonized as EN 60204-1:1992 (modified). Although the title of IEC 60204 indicates that its use is restricted to “industrial machines”, the scope of EN 60204 has been broadened to include those machines covered by the EEC Directives relating to safety of machinery. This change is reflected in the title of EN 60204.

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

Note: Harmonized as EN 60601-2-22:1992 (not modified)

IEC 60950:1999, *Safety of information technology equipment*

Note: Harmonized as EN 60950:1992 + A1:1993 + A2:1993 (modified)

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

Note: Harmonized as EN 61101-1:1993 (modified)

Annex G
(informative)

Information to be provided by manufacturers of LEDs

This annex provides a listing of the radiometric specifications of Light Emitting Diodes (LEDs). The provision of these specifications by manufacturers of LEDs will be of use to manufacturers of equipment using those LEDs in complying with the requirements of IEC 60825-1. In this annex LED includes infrared emitting diodes.

The manufacturer of LEDs should provide the following data using the upper one-sided 95 % confidence limit values where appropriate (see note 1). Electrical and optical characteristics for LEDs should be specified according to IEC 60747-5-2, IEC 60747-12-1 and IEC 60747-12-3.

G.1 Minimum data required for components intended for inherent Class 1 operation

- Statements of the operating conditions under which Class 1 operation is ensured. This allows the equipment manufacturer to determine compliance with IEC 60825-1 by analysis of the circuit used to drive the LED without test of the product that incorporates the LED.

G.2 Essential data if component is not inherently Class 1 (parametric)

- Peak wavelength, in nanometres
- Divergence, half-intensity angle in degrees
- Apparent source size, in millimetres (or angular subtense, in milliradian) using power measurement method in 8.2 of IEC 60825-1
- Location of apparent source, in millimetres (from a stated reference surface)
- Radiance, $W \cdot m^{-2} sr^{-1}$
- Radiant intensity, min. and max. $W \cdot sr^{-1}$
- Reference temperature of data (normally 25 °C) (see note 2)
- Physical identification (for example, package profile, lead-outs, dimensions, etc.)

G.3 Essential data if component is not inherently Class 1 (graphical or tabular)

- Radiant intensity, $W \cdot sr^{-1}$ versus input current, in milliamperes
- Spectral distribution, relative emission versus wavelength
- Temperature dependence of peak wavelength
- Temperature dependence of radiant intensity (at a stated current)
- Information of intensity distribution as a function of emission angle
- Burn-out time versus current (see note 8)

G.4 Additional data to assist safety assessment

- Statement of the intended use of the LED, for example, intended as an indicating surface-emitting LED or for other use (see note 3).

NOTE 1 Confidence limits provide the statistical rationale that the values stated are those which result in the maximum hazard, taking into account variations among actual devices and measurement uncertainties.

NOTE 2 25 °C is normal room temperature and is intended to provide a common reference that can be used to compare devices from all manufacturers. The temperature dependence data will allow assessment to be made for different conditions of use.

NOTE 3 A surface-emitting LED in this context is a component without gain where the emission from the component surface can be viewed directly. It may have a built-in lens or reflector.

NOTE 4 Where the LED wavelength is selected by polarity, for example, a two-colour red/green LED, the device shall be evaluated according to IEC 60825-1 for each wavelength.

NOTE 5 Where the LED is capable of emitting at different wavelengths simultaneously, the device shall be evaluated according to IEC 60825-1 as a multiple wavelength emitter.

NOTE 6 For an array of multiple LEDs, the array group shall be evaluated according to IEC 60825-1, annex A.2, example A.2.4.

NOTE 7 The LED Class should normally be based on continuous operation unless it is known that the LED device will fail within a particular time, or unless the device emission duration is limited in the end application.

NOTE 8 It is possible that an LED will have a much larger current flowing through it under fault conditions within the end equipment. When over-driven, an LED will emit a higher radiated output but the excess current may cause the device to burn out within a certain time. By providing information on the time taken for a device to burn out at specified currents, the end equipment manufacturer may determine the LED Class of their equipment under fault conditions.

G.5 Reference documents

IEC 60747-5-2:1997, *Discrete semiconductor devices and integrated circuits – Part 5-2: Optoelectronic devices – Essential ratings and characteristics*

IEC 60747-12-1:1995, *Semiconductor devices – Part 12: Optoelectronic devices – Section 1: Blank detail specification for light emitting/infrared emitting diodes with/without pigtail for fibre optic systems and sub-systems*

IEC 60747-12-3:1998, *Semiconductor devices – Part 12-3: Optoelectronic devices – Blank detail specification for light-emitting diodes – Display application*

Annex H
(informative)

Overview of associated parts of IEC 60825

The associated parts of IEC 60825 are intended for use in conjunction with the basic standard IEC 60825-1. Each part covers a defined scope and provides additional normative and informative guidance to enable the manufacturer and user to correctly classify and use the product in a safe manner by taking account of the particular conditions of use and competence/training of the operator/user. The information covered may include rationale, examples, clarification, methods, labelling, and any additional limits and requirements.

Table H.1 – Overview of additional data in associated parts of IEC 60825

Part No.	Type	Description	Product designer	Product supplier	Product user	Safety critical component supplier	Test methods	Hazard assessment	Related standards
1	Standard	Equipment classification, requirements and user's guide	Yes	Yes	Yes	Yes	Yes	Yes	
2	Standard	Safety of optical fibre communication systems (provides application notes and examples)	Yes	Yes	Yes	Yes	Yes	Yes	
3	Technical report	Guidance for laser displays and shows	No	No	Yes	No	No	Yes	
4	Standard	Laser guards (also addresses ability of high-power lasers to remove guard material)	Yes	Yes	Yes	Yes	Yes	Yes	
5	Technical report	Manufacturer's checklist for IEC 60825-1 (suitable for use in a safety report)	Yes	Yes	No	Yes	No	No	
6	Technical specification	Safety of products with optical sources, exclusively used for visible information transmission to the human eye (includes indicating LEDs)	Yes	Yes	No	Yes	Yes	Yes	
7	Technical specification	Safety of products emitting 'infrared' optical radiation, exclusively used for wireless 'free air' data transmission and surveillance (NOHD <2,5 m)	Yes	Yes	No	Yes	Yes	Yes	
8	Technical report	Guidelines for the safe use of medical laser equipment	No	No	Yes	No	No	No	IEC 60601-2-22
9	Technical report	Compilation of maximum permissible exposure to incoherent optical radiation (broadband sources)	No	No	Yes	No	Yes	Yes	
10	Technical report	Laser safety application guidelines and explanatory notes	Yes	Yes	No	No	Yes	No	ISO 13694

NOTE This table is intended to provide an indication of content – see text of the particular standard for complete requirements. Some parts listed above may be under discussion by working groups and may not be formally published.

Annex ZA (normative)
Other international publications quoted in this standard with the references of the relevant European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

NOTE When the international publication has been modified by CENELEC common modifications, indicated by (mod), the relevant EN/HD applies.

IEC publication	Date	Title	EN/HD	Date
60027-1	1992[a]	*Letter symbols to be used in electrical technology — Part 1: General*	—	—
60050(845)	1987	*International Electrotechnical Vocabulary (IEV) — Chapter 845: Lighting*	—	—
60601-2-22	1992	*Medical electrical equipment — Part 2: Particular requirements for the safety of diagnostic and therapeutic laser equipment*	EN 60601-2-22	1992
60825-2	1993	*Safety of laser products — Part 2: Safety of optical fibre communication systems*	EN 60825-2	1994
61010-1 A1 (mod)	1990 1992	*Safety requirements for electrical equipment for measurements, control and laboratory use — Part 1: General requirements*	EN 61010-1	1993
61040	1990	*Power and energy measuring detectors, instruments and equipment for laser radiation*	EN 61040	1992
Other publications				
ISO 1000	1992	*SI units and recommendations for the use of their multiples and of certain other units*	—	—

[a] IEC 60027-1:1971 + A1:1974 + A2:1977 was harmonized as HD 245.1 S3:1979.

National annex NA (informative) Committees responsible

The United Kingdom participation in the preparation of this European Standard was entrusted by the Electrotechnical Sector Board to Technical Committee EEL/28, upon which the following bodies were represented:

Association of University Radiation Protection Officers

BLWA Ltd. (The Association of the Laboratory Supply Industry)

British Medical Laser Association

British Railways Board

British Telecommunications plc

Department of Health

Department of Trade and Industry (Consumer Safety Unit, CA Division)

Engineering Equipment and Materials Users' Association

Federation of the Electronics Industry

Health and Safety Executive

Institute of Physics

Institute of Electrical Engineers

Machine Tool Technologies Association

Ministry of Defence

National Radiological Protection Board

Royal College of Ophthalmologists

Royal Institute of Chartered Surveyors

SIRA Ltd.

Trades Union Congress

UK Optical Sensors Collaborative Association

UK Laser and Electro-optic Association

blank

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001. Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL