

Australian/New Zealand Standard™

Safety of laser products

Part 14: A user's guide



AS/NZS IEC 60825.14:2011

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PREFACE

This document was prepared by the Joint Standards Australia/Standards New Zealand Committee SF-019, Personal Protection Against Laser Radiation, to supersede Section 3 of AS/NZS 2211.1:2004, *Safety of laser products*, Part 1: *Equipment classification, requirements and user's guide*. AS/NZS 2211.1:2004 was a modified adoption of IEC 60825-1:2001, which incorporated a user's guide as Section 3 of the Standard. The 2007 revision of IEC 60825-1 relocated the user's guide into a new part of the series, IEC/TR 60825-14.

This document is identical with, and has been reproduced from IEC/TR 60825-14, Ed.1.0 (2004), *Safety of laser products—Part 14: A user's guide*.

The objectives of this document are as follows:

- (a) To protect people from laser radiation in the wavelength range 180 nm to 1 mm by indicating safe working levels of laser radiation.
- (b) To help users understand the general principles of laser safety management and use manufacturer supplied information to develop proper precautions and establish procedures to mitigate risks.
- (c) To provide a framework for users to identify and evaluate hazards and assess the risks in order to set up and maintain appropriate control measures.
- (d) To reduce the possibility of injury by minimizing unnecessary exposure to radiation and to provide safe usage of laser products by specifying user control methods.
- (e) To protect people against other hazards resulting from the operation and use of laser products.

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The term 'informative' has been used in this document to define the application of the annex to which it applies. An 'informative' annex is only for information and guidance.

Standards in the IEC 60825 series may have been adopted as either AS/NZS IEC 60825 series standards, e.g. IEC/TR 60825-14 has been adopted as AS/NZS IEC 60825.14, or AS/NZS 2211 series standards, e.g. IEC 60825-4 has been adopted as AS/NZS 2211.4.

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INTRODUCTION

To help in the use of this technical report, an outline of the topics that are covered within it is given below. The topics are presented in the order in which they would normally be considered as part of a laser safety programme.

- Safety responsibilities with regard to the operation of lasers and the need for appropriate training are covered in Clause 3.
- The meaning of the laser product classes and the assessment of laser exposure are covered in Clause 4.
- The determination of the maximum permissible exposure (MPE), and the concept of the hazard distance and hazard zone within which the MPE can be exceeded, are covered in Clause 5.
- Associated laser hazards (that is, hazards other than those of eye or skin exposure to the emitted laser beam) are covered in Clause 6.
- A three-stage process for evaluating risk (arising from both the laser radiation hazards discussed in Clauses 4 and 5, and the associated laser hazards discussed in Clause 6) is covered in Clause 7. These three stages are:
 - 1) the identification of all potentially injurious situations,
 - 2) the assessment of the risk arising from these situations and
 - 3) the determination of the necessary protective measures.
- The use of control measures for reducing the risk to an acceptable level is covered in Clause 8.
- The need to ensure the continuation over time of safe laser operation is covered in Clause 9.
- The reporting of laser-related hazardous incidents and the investigation of accidents is covered in Clause 10.
- The role of medical surveillance (eye examinations) is covered in Clause 11.
- Additional information on the use of interlock protection is given in Annex A.
- Examples of laser safety calculations are given in Annex B.
- An explanation of the biophysical effects of laser exposure to the eyes and skin is given in Annex C.

AUSTRALIAN/NEW ZEALAND STANDARD

Safety of laser products

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1 Scope and object

This technical report provides guidance on best practice in the safe use of laser products that conform to IEC 60825-1. The terms "laser product" and "laser equipment" as used in this document also refer to any device, assembly or system, which is capable of emitting optical radiation produced by a process of stimulated emission. However, unlike IEC 60825-1, this document does not cover light-emitting diodes (LEDs).

Class 1 laser products normally pose no hazard and Class 2 laser products present only a minimal hazard. With these products, it is normally sufficient to follow the warnings on the product labels and the manufacturer's instructions for safe use. Further protective measures as described in this document should not be necessary.

This document emphasizes evaluation of the risk from higher power lasers, but the users of the lower power lasers may benefit from the information contained. See Table 1 for an overview.

This technical report can be applied to the use of any product that incorporates a laser, whether or not it is sold or offered for sale. Therefore, it applies to specially constructed lasers (including experimental and prototype systems).

This technical report is intended to help laser users and their employers to understand the general principles of safety management (Clause 3), to identify the hazards that may be present (Clauses 4 to 6), to assess the risks of harm that may arise (Clause 7), and to set up and maintain appropriate control measures (Clauses 8 to 11).

Laser control measures vary widely. They depend on the type of laser equipment in use, the task or process being performed, the environment in which the equipment is used and the personnel who may be at risk of harm. Specific requirements for certain laser applications is given in other documents in the IEC 60825 series (see the Foreword or bibliography for the titles of these documents).

The terms "reasonably foreseeable" and "reasonably foreseeably" are used in this document in relation to certain specific events, situations or conditions. It is the responsibility of the person using this document to determine what is "reasonably foreseeable" and what might occur "reasonably foreseeably", and to be able to defend, on the basis of risk-assessment criteria, any such judgements that are made.

Reference is made in this document to laser "users". This should be taken to include persons having responsibility for safety in addition to those who actually work with or operate laser equipment.

2 Terms and definitions

For the purposes of this document, the following definitions apply.

2.1

administrative control

safety measures of a non-engineering type such as key supervision, safety training of personnel, warning notices, countdown procedures, and range safety controls

2.2

alpha min

α min

See angular subtense (2.4)

2.3

angle of acceptance

γ

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

NOTE 1 The angle of acceptance is also sometimes referred to as the field of view.

NOTE 2 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.

2.4

angular subtense

α

angle subtended by an apparent source as viewed at a point in space

NOTE 1 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). For an analysis of the maximum permissible exposure levels, the angular subtense is determined at the viewing distance from the apparent source but not less than 100 mm.

NOTE 2 The angular subtense of an apparent source is applicable in this part of IEC 60825 only in the wavelength range from 400 nm to 1 400 nm, the retinal hazard region.

NOTE 3 The angular subtense of the source should not be confused with the divergence of the beam.

2.5

aperture

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

2.5.1

aperture stop

opening serving to define the area over which radiation is measured

2.6

apparent source

real or virtual object that forms the smallest possible retinal image

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

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

2.7

beam

laser radiation that may be characterized by direction, divergence, diameter or scan specifications

NOTE Scattered radiation from a non-specular reflection is not considered to be a beam.

2.8

beam attenuator

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

2.9

beam diameter

d_u

beam width

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.

2.10

beam divergence

far field plane angle of the cone defined by the beam diameter

NOTE 1 If the beam diameters at two points separated by a distance r are d_{63} and d'_{63} , the divergence is given by:

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

NOTE 2 SI unit: radian.

2.11

beam stop

device which terminates a laser beam path

2.12

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

2.13

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, where the level of radiation is measured but is evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 1 laser products

NOTE The output of a Class 1M product is therefore potentially hazardous when viewed using an optical instrument.

2.14

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

2.15**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, where the level of radiation is measured but is evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 2 laser products

NOTE The output of a Class 2M product is therefore potentially hazardous when viewed using an optical instrument.

2.16**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

2.17**Class 4 laser product**

any laser product which permits human access to laser radiation in excess of the accessible emission limits of Class 3B

2.18**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

2.19**collimated beam**

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

2.20**continuous wave****CW**

output of a laser which is operated in a continuous rather than pulsed mode. In this part of IEC 60825, a laser operating with a continuous output for a period equal to or greater than 0,25 s is regarded as a CW laser

2.21**defined beam path**

an intended path of a laser beam within the laser product

2.22**diffuse reflection**

change of the spatial distribution of a beam of radiation by scattering in many directions by a surface or medium.

NOTE 1 A perfect diffuser destroys all correlation between the directions of the incident and emergent radiation.

NOTE 2 This definition is different from IEC 845-04-47.

2.23**embedded laser product**

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.

2.24**emission duration**

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

2.25**exposure duration**

see exposure time (2.26).

2.26**exposure time**

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

2.27**extended source viewing**

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 ($\alpha_{\min}$)

NOTE 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 $\alpha_{\min}$ and $\alpha_{\max}$ (intermediate sources), and greater than $\alpha_{\max}$ (large sources).

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

2.28**fail safe**

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

2.29**human access**

- a) capability of a part of the human body to meet hazardous laser radiation either as emitted from an aperture, or capability of 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

2.30**integrated radiance**

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 as $J \cdot m^{-2} \cdot sr^{-1}$)

2.31**intrabeam viewing**

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

2.32**irradiance** **E**

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

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

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

2.33**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 IEC 845-04-39.

2.34**laser controlled area**

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

2.35**laser energy source**

any device intended for use in conjunction with a laser to supply energy for the excitation of electrons, ions, or molecules.

NOTE General energy sources such as electrical supply mains or batteries are not considered to constitute laser energy sources.

2.36**laser equipment**

laser product – an assembly that is or contains a laser

2.37**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

2.38**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

2.39**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

2.40**laser system**

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

2.41**limiting aperture**

circular area over which irradiance and radiant exposure are averaged

2.42**maintenance**

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

2.43**maximum angular subtense** **$\alpha_{\max}$**

value of angular subtense of the apparent source above which the MPEs are independent of the source size

2.44**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

NOTE 1 The values for maximum permissible exposure used in this document are those recommended by the International Commission on Non-Ionizing Radiation Protection, and are based on the current state of knowledge of threshold levels for laser injury.

NOTE 2 Annex B gives examples of the calculations of MPE levels.

2.45**minimum angular subtense** **$\alpha_{\min}$**

value of angular subtense of the apparent source above which a source is considered an extended source

NOTE MPEs are independent of the source size for angular subtenses less than $\alpha_{\min}$.

2.46**nominal ocular hazard area****NOHA**

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

NOTE If the NOHA includes the possibility of viewing through optical aids, this is termed the "extended NOHA".

2.47**nominal ocular hazard distance****NOHD**

distance at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE)

NOTE If the NOHD includes the possibility of optically-aided viewing, this is termed the "extended NOHD".

2.48**operation**

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

2.49**optical density****OD**

logarithm to base ten of the reciprocal of the transmittance τ

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

2.50**photochemical hazard limit**

MPE that was derived to protect persons against adverse photochemical effects

NOTE An example of such adverse effects is photoreinitis, a photochemical retinal injury from exposure to radiation in the wavelength range from 400 nm to 600 nm.

2.51**protective enclosure**

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

2.52**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 level required by the laser product's prescribed classification (generally installed by a manufacturer)

2.53**pulse duration**

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

2.54**pulsed laser**

laser which delivers its energy in the form of a single pulse or a train of pulses. In this part of IEC 60825, the duration of a pulse is less than 0,25 s

2.55**radiance**

L

quantity defined by the formula

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

where

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

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

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

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

NOTE 2 This definition is a simplified version of IEC 845-01-34, sufficient for the purpose of this part. In cases of doubt, the IEC definition should be followed.

2.56**radiant energy**

Q

time integral of the radiant flux over a given duration Δt

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

NOTE SI unit: joule (J).

(IEC 845-01-27)

2.57**radiant exposure** **H**

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

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

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

2.58**radiant power****radiant flux** **Φ, P**

power emitted, transferred, or received in the form of radiation

$$\Phi = \frac{dQ}{dt}$$

NOTE SI unit: watt (W).

2.59**reflectance** **ρ**

ratio of the reflected radiant power to the incident radiant power in the given conditions

NOTE SI unit: 1.

2.60**remote interlock connector**

connector which permits the connection of external controls placed apart from other components of the laser product

2.61**safety interlock**

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

2.62**service**

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

2.63**single fault condition**

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

2.64**small source**

source with an angular subtense α less than, or equal to, the minimum angular subtense $\alpha_{\min}$

2.65**specular reflection**

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

2.66**thermal hazard limit**

MPE that was derived to protect persons against adverse thermal effects, as opposed to photochemical injury

2.67**time base**

emission duration to be considered for classification

2.68**tool**

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

2.69**transmittance**

τ

ratio of the transmitted radiant flux to the incident flux in the given conditions

NOTE SI unit: 1.

2.70**visible radiation (light)**

any optical radiation capable of causing a visual sensation directly

NOTE In this part of IEC 60825, this is taken to mean electromagnetic radiation for which the wavelength of the monochromatic components lies between 400 nm and 700 nm.

3 Administrative policies**3.1 Safety responsibilities**

Safety responsibilities may be specified by national or local regulations. These specific responsibilities should be followed. However, in the absence of any specific legislation or regulations, the following are some general guides on responsibilities for the safe use of lasers.

Employers and employees, and all users of lasers (including students) and those supervising or overseeing them, have a role to play in maintaining a safe place of work and in ensuring that their activities do not present unacceptable levels of risk to themselves or to others.

In any place of work in which lasers are in use, it is the employer's responsibility to ensure that the risks to health arising from the use and reasonably foreseeable misuse of laser equipment are properly assessed. The employer must take all necessary steps to ensure that these risks are either eliminated or, where this is not reasonably practicable, reduced to an acceptably low level.

Wherever potentially hazardous lasers are in use, the employer (or any other person having overall responsibility) should establish a general policy for the safe management of these hazards, although specific safety tasks may be delegated to others. This policy, which should be an integral part of the organisation's overall safety policy, should require that all reasonably foreseeable hazards arising from laser use are identified and that steps are taken to control them so far as is reasonably practicable. Significant findings of this assessment should be documented and appropriate protective measures implemented wherever necessary to reduce the identified health and safety risks. The effectiveness of such protective measures should be reviewed regularly. These requirements for establishing a specific safety policy for lasers are not normally necessary where only laser products in Class 1 or Class 2 are in use, and may not always be necessary for laser products in Class 1M or Class 2M, but see Table 1 concerning protective control measures, 4.1.3 concerning embedded lasers and 4.2.2 concerning temporary visual effects.

3.2 Competent persons

Where the employer or laser user is not able, without assistance, to properly determine the necessary safety arrangements and protective measures for eliminating or minimising the risks to health arising from the use of laser equipment, then the advice of a Competent Person should be sought. The Competent Person should have sufficient skill in, and knowledge and experience of, matters relevant to laser safety, and should provide appropriate assistance to the employer (or to the employer's delegated representative, or laser user) in hazard determination, risk assessment, and protective control and procedure provision.

The Competent Person need not be an employee of the organisation concerned, but may instead be an external adviser. The advice and assistance of a Competent Person is often only necessary temporarily, for example when first establishing appropriate protective control measures or when evaluating the risk prior to significant changes to procedures or equipment.

3.3 Laser Safety Officer

A Laser Safety Officer should be appointed in organisations in which Class 3B or Class 4 laser products are in use. The appointment of a Laser Safety Officer is also recommended where Class 1M and Class 2M laser products generating well-collimated beams are in use, and which could present a hazard if viewed through binoculars or telescopes at a considerable distance from the laser. (This can include the installation and servicing of embedded lasers where access may be gained to higher levels of laser radiation than is implied by the laser product's class (see 4.1.3), or where the use of lasers of a lower class than 3B or 4 may nevertheless still introduce a significant risk, perhaps through the involvement of untrained people or because of the existence of associated laser hazards – see Clause 6.)

The Laser Safety Officer should take responsibility, on behalf of the employer, for the administration of day-to-day matters of laser safety. It is the employer's responsibility to ensure that the person appointed as Laser Safety Officer has sufficient competence and capability to perform this role satisfactorily. Suitable training should be provided if necessary.

The duties of the Laser Safety Officer should be agreed with the employer (or with the employer's delegated representative) and documented. These duties should be those necessary to ensure the continuing safe use of lasers within the organisation concerned, but are likely to include as a minimum:

- a) being aware of and, if appropriate, maintaining records of, all potentially-hazardous laser products (including the identification, specification, class and purpose of the laser product; the location of the laser product; and any special requirements or restrictions relating to its use);
- b) responsibility for monitoring compliance with the organisation's procedures for ensuring safe laser use, for maintaining appropriate written records, and for taking immediate and appropriate action in respect of any non-compliance or apparent inadequacy in such procedures.

Whether the Laser Safety Officer can authorise, or merely recommend to a person having such authority, the termination of unsafe practices and the implementation of corrective actions should be agreed and specified in the documented duties.

The role of Laser Safety Officer rarely needs to be a full-time appointment. Where a Competent Person (see 3.2) has been appointed and that person is an employee of the organisation concerned (often desirable in organisations having extensive and varied laser use), then the Competent Person may also be the Laser Safety Officer.

In large organisations where there is extensive laser use, suitable employees may be appointed to act as local-area or departmental laser safety representatives in order to assist the Laser Safety Officer and to ensure, on behalf of the employer, safe laser use throughout the organisation. (The titles Laser Safety Officers and Senior Laser Safety Officer may be used, respectively, instead.) In such circumstances, regular liaison should be maintained between these people to ensure the consistent and effective overall management of the laser safety programme.

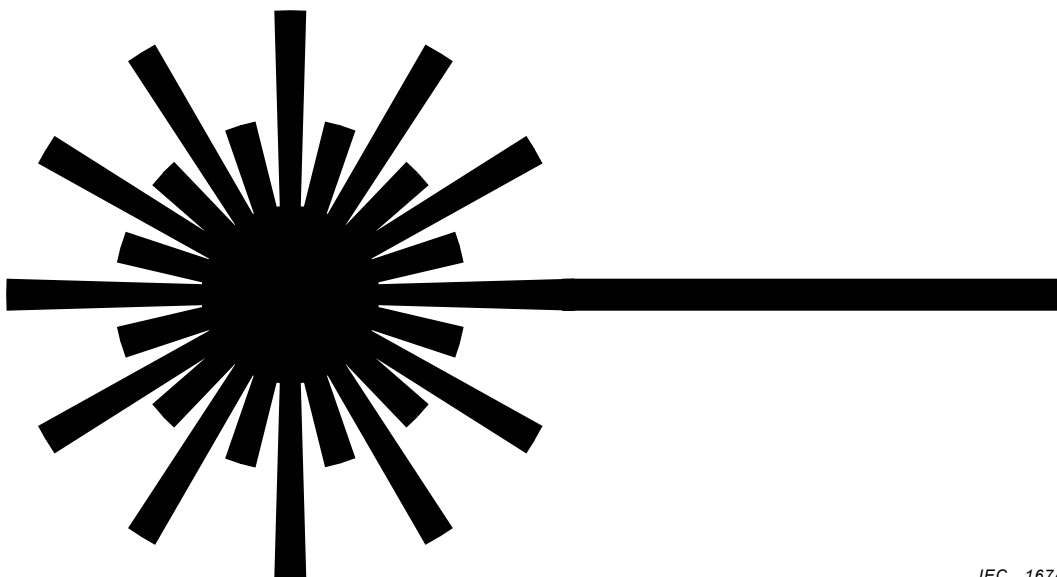
3.4 Information and training

All employees should, where relevant, be made aware of any hazards (including associated hazards; see Clause 6) to which they may be exposed during the use of laser equipment, and of the procedures necessary to ensure protection. Adequate warnings should be displayed. These warnings should include the laser hazard symbol shown in Figure 1 with appropriate wording. Sufficient instruction or training should be given in order that employees have the necessary understanding to avoid placing themselves and others at unacceptable risk. Safety training is especially important for those who work with Class 3B or Class 4 laser products.

Such instruction and training should be commensurate with the type of hazard and appropriate for the employees concerned. It should include, but need not be limited to:

- a) the organisation's policy for safe laser use;
- b) the risks of harm that could arise from the use and reasonably foreseeable misuse of the laser equipment;
- c) the meaning of displayed warning signs;
- d) the correct use and operation of the laser equipment, and of associated equipment, including personal protective equipment (where applicable – see 8.4.5);
- e) working procedures and local rules;
- f) the procedures to be followed in the event of an actual or suspected accident or other safety-related incident.

Instruction and training should be completed prior to operating or working with laser products, and repeated as frequently as necessary in order to ensure continuing compliance with safety procedures. Records of training should be kept.



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Figure 1 – Laser hazard symbol

4 Laser radiation hazards

4.1 Laser products

4.1.1 Laser product classification

The class of a laser product gives an indication to the user of the potential of the accessible laser radiation for causing injury. All laser equipment, whether commercially produced or not, should therefore be classified in accordance with the provisions of IEC 60825-1, and labelled appropriately to inform the user of the class assigned. Classification of laser products is normally done by the manufacturer of the laser product, but where this is not the case (e.g., laser components, experimental or prototype systems), then the user should ensure that the effective class of the laser is determined based on the level of its accessible emission in accordance with IEC 60825-1.

If the user incorporates a laser into other equipment, then the complete equipment should itself be considered a laser product and be classified accordingly (see 4.1.3). In addition, it should be recognised that some or all of the original safety features of the incorporated laser product, including labelling, and which are intended to satisfy the manufacturing requirements specified in IEC 60825-1, may be inoperative, unusable or inaccessible because of the way in which the laser has been incorporated into the equipment. Where necessary to ensure safe operation, these safety features should be replicated or replaced.

4.1.2 Product classes

The classification of a laser gives an indication of its potential hazard. Laser product classification is based on the maximum level of laser radiation that is accessible during conditions of normal operation. Associated hazards (see Clause 6) that may also be present during use of the laser do not affect the laser classification.

The laser product classes are outlined below, together with a brief description of the protection requirements that should normally be satisfied for each product class. Except for Classes 2 and 2M, the emitted radiation may be visible or invisible. (For more complete details of classification, IEC 60825-1 should be consulted.)

a) Class 1

Laser products which are normally safe under reasonably foreseeable conditions of use, either because of the inherently low emission of the lasers themselves, or because they are totally enclosed and human access to higher levels of internal laser radiation is not possible during normal operation.

Protection requirements for Class 1: Ensure that the conditions for Class 1 operation are maintained (see 4.1.3). If access to levels of laser radiation in excess of the limits for Class 1 could occur, for example during servicing of an embedded laser product, or in the case of an expanded-beam laser by using external optics to reduce the size or divergence of the emitted beam then the protection requirements of the appropriate higher class apply.)

b) Class 1M

Laser products which exceed the permitted accessible emission limits for Class 1 but which, because of the geometrical spread of the emitted radiation, cannot cause harmful levels of exposure to the unaided eye. However, the safe limit for ocular exposure can be exceeded, and injury can occur, if magnifying viewing instruments are used. Such instruments include binoculars and telescopes in the case of large-diameter collimated beams, or magnifying lenses and microscopes in the case of highly divergent beams. Hazardous exposure can also occur if the dimensions of the laser beam (its diameter or divergence) are reduced by the use of optical components in the beam path.

Protection requirements for Class 1M: Avoid the use of magnifying viewing aids or instruments (such as binoculars, telescopes, microscopes and magnifying lenses, but not spectacles or contact lenses). Avoid placing optical devices in the emitted beam that could cause the concentration of the laser radiation to be increased. Do not direct the beam into areas where other people may be present if there is a likelihood of the people in those areas using telescopes or binoculars to look directly into the beam.

c) **Class 2**

Laser products emitting low-levels of visible radiation (that is, at wavelengths between 400 nm and 700 nm) which are safe for the skin but which are not inherently safe for the eyes, but for which eye protection is normally afforded by natural aversion responses to bright light. Accidental eye exposure is therefore normally safe, although the natural aversion response can be overridden intentionally by deliberately staring into the beam, and can be influenced by taking alcohol or drugs.

Protection requirements for Class 2: Avoid staring into the beam (i.e. deliberate viewing of the laser source) or pointing the beam at other people.

d) **Class 2M**

Laser products emitting levels of visible radiation that exceed the permitted accessible emission limits for Class 2 but for which, because of the geometrical spread of the emitted radiation, protection of the unaided eye is normally afforded by natural aversion responses to bright light. However, the aversion response may not provide sufficient protection, and injury can occur, if magnifying viewing instruments are used. Such instruments include binoculars and telescopes in the case of large-diameter collimated beams, or magnifying lenses and microscopes in the case of highly divergent beams. Hazardous exposure can also occur if the dimensions of the laser beam (its diameter or divergence) are reduced by the use of optical components in the beam path.

Protection requirements for Class 2M: Avoid the use of magnifying viewing aids or instruments (such as binoculars, telescopes, microscopes and magnifying lenses, but not spectacles or contact lenses). Avoid placing optical devices in the emitted beam, which could cause the concentration of the laser radiation to be increased. Avoid staring into the beam (i.e. deliberate viewing of the laser source) or pointing the beam at other people.

e) **Class 3R**

Laser products having a level of accessible emission up to five times the limits for Class 1 (if invisible) or Class 2 (if visible). The maximum permissible exposure may be exceeded but the risk of injury is low.

Protection requirements for Class 3R: Prevent direct eye exposure to the beam or pointing the beam at other people.

f) **Class 3B**

Laser products having a level of accessible emission, which can be harmful to the eyes, whether magnifying viewing aids are used or not. Class 3B laser products can also be harmful to the skin at output levels approaching the upper limit of this class.

Protection requirements for Class 3B: Prevent eye (and in some cases skin) exposure to the beam. Guard against unintentional beam reflections.

g) **Class 4**

Laser products having a level of accessible emission, which can be harmful to both the eyes and the skin. Diffuse reflections of the laser radiation may also be hazardous. The laser emission can also be sufficient to ignite material, on which it impinges, and to generate harmful radiation or fume hazards by interaction with target materials.

Protection requirements for Class 4: Prevent eye and skin exposure to the beam, and to diffuse reflections (scattering) of the beam. Protect against beam interaction hazards such as fire and fume.

End use laser products in classes 2, 2M, 3R, 3B and 4 which are supplied in accordance with IEC 60825-1 will carry warning labels indicating the class and the basic precautions to be followed. Laser products in classes 1 and 1M may also carry labels, but at the discretion of the manufacturer, the required wording can instead be included in the user information.

It is recommended that unlabelled lasers (including component lasers or user-modified systems) that are in regular use be appropriately labelled in accordance with the labelling requirements of IEC 60825-1.

In many applications where the laser products in use are no higher than Class 3R (i.e. they are Class 1, 1M, 2, 2M or 3R), the user may implement control measures based on the highest class of laser product in use without any need to undertake a detailed risk assessment or to evaluate possible levels of human exposure. These default control measures are summarised in Table 1 as a function of the laser class.

It may often be necessary, however, for a more detailed analysis to be undertaken in order to determine the protective measures that are appropriate. Such circumstances include:

- all uses of laser products in Class 3B or 4,
- the use of protective eyewear,
- reliance for protection on the concept of a minimum safe distance from the laser, and
- other situations where the controls specified in Table 1 may be inappropriate, insufficient or unreasonably restrictive given the actual degree of risk.

NOTE Many older laser products will be classified under the previous scheme of Classes 1, 2, 3A, 3B and 4. IEC 60825-1 may be used to determine the class that the product would be in under the current system of classification. The majority of laser products in classes 1, 2, and 4 will, however, be unaffected.

Table 1 – Default protective control measures for laser products

CLASS	PROTECTIVE CONTROL MEASURES These should be implemented unless a risk assessment justifying the adoption of alternative protective control measures has been undertaken.
1	No protective control measures are necessary under conditions of normal operation. (This may not be the case under conditions of maintenance or service.) In the case of embedded laser products containing a laser of higher power, follow instructions given on warning labels and supplied by the manufacturer. Special precautions may be needed for on-site servicing of embedded laser products (see 8.5).
1M	Prevent direct viewing of the laser source through magnifying viewing instruments, such as binoculars, telescopes, microscopes, optical sights or magnifying lenses, unless these incorporate adequate levels of protection ^a . Prevent the use of any external optics that could decrease the beam divergence or its diameter.
2	Do not stare into the beam. Do not direct the beam at other people or into areas where other people unconnected with the laser work might be present.
2M	Do not stare into the beam. Do not direct the beam at other people or into areas where other people unconnected with the laser work might be present. Ensure the beam is always terminated at a suitable non-specular (i.e. non mirror-like) surface. Prevent direct viewing of the laser source through magnifying viewing instruments, such as binoculars, telescopes, microscopes, optical sights or magnifying lenses, unless these incorporate adequate levels of protection ^a . Prevent the use of any external optics that could decrease the beam divergence or its diameter.
3R	Prevent direct eye exposure to the beam. Do not direct the beam at other people or into areas where other people unconnected with the laser work may be present.
3B and 4	Class 3B and Class 4 laser products should not be used without first carrying out a risk assessment to determine the protective control measures necessary to ensure safe operation. Where reasonably practicable, use engineering means, as specified in IEC 60825-1, to reduce the class of the laser to below Class 3B. (This will normally mean completely enclosing the laser radiation to form a Class 1 laser product.)
^a The type of viewing instrument that could be hazardous may be indicated on the warning label or in the user information supplied by the manufacturer.	

4.1.3 Embedded lasers

Since laser products are classified based on the level of laser radiation that is accessible during normal operation, a laser product of one class may contain an embedded (i.e. enclosed) laser of a higher class. This is most commonly encountered in the case of a product assigned to Class 1 but which incorporates an embedded laser that has been totally enclosed in a manner satisfying the manufacturing requirements of IEC 60825-1. Opening, removal or displacement of any part of an enclosure that is not designed to be opened, removed or displaced during operation may therefore give access to harmful levels of laser radiation. Procedures for the servicing of embedded lasers are discussed in 8.5.

Examples of Class 1 products that incorporate embedded lasers but have no accessible laser emission during normal operation include compact disc (CD) players, laser printers, and totally-enclosed industrial machining lasers. Examples of embedded laser products that have accessible laser emission include certain scanning lasers (such as bar code readers) where the rapidly moving beam may place the product in a lower class than would be the case for a stationary beam, and lasers employing various optical systems that expand or spread the emitted beam, thereby making it less hazardous.

IEC 60825-1 requires that, during operation for its intended function, the designated class of a laser product should be applicable under the maximum level of accessible emission and under all reasonably foreseeable single fault conditions. Some products, within any class other than Class 4, may incorporate a laser having accessible emission that is constrained within that class by the design of the electronic drive circuitry or by other means, even though the laser itself is capable of generating a level of emission that would place it in a higher class. Users of such products should therefore be aware that under a combination of fault conditions, or when used in a manner other than that intended by the manufacturer, higher levels of laser radiation can become accessible. The user should refer to the manufacturer's operating instructions in order to avoid exposure to potentially hazardous laser radiation.

4.1.4 Optical fibres

Optical fibres carrying laser radiation normally provide a complete enclosure of the radiation, and so prevent access to it. However, if a fibre is disconnected or a fibre break occurs, hazardous levels of laser exposure can be present.

Safety requirements specifically applicable to optical fibre communication systems are defined in IEC 60825-2. These requirements include the necessity for assessing the potential level of accessible laser emission from an optical fibre in terms of the *hazard level* (e.g., hazard level 1, 1M, 2, 2M, 3R, 3B or 4), equivalent to product class. The hazard level applies only to a particular location at which an interruption of the fibre might reasonably foreseeably occur, rather than to the complete system or installation as a whole. It is therefore possible that different locations at which access to fibre emission could occur within the same system may be assigned different hazard levels. This is not possible for product class, which is based on the highest level of accessible emission from a complete laser product.

4.1.5 Laser demonstrations and displays

Only Class 1, Class 2, or visible-beam Class 3R laser products should normally be used for demonstration, display, or entertainment purposes in unsupervised areas.

The use of other classes of laser products for such purposes should be permitted only:

- 1) after a risk assessment has been carried out to determine the protective control measures that are necessary;
- 2) 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 maximum permissible exposure (MPE).

IEC 60825-3 gives specific guidance for laser displays and shows, although many countries have issued their own national guidelines.

4.2 Exposure to laser radiation

4.2.1 Maximum permissible exposure

One of the principal aims of a laser safety programme is to ensure that any exposure to laser radiation that might occur is within safe limits. It is therefore often necessary to assess the maximum level of exposure that could arise under all foreseeable conditions (as discussed in 4.3), and then to relate this to the maximum permissible exposure (the MPE, outlined below and explained in more detail in Clause 5).

NOTE The need to ensure that levels of exposure to laser radiation do not exceed the MPE is not applicable to the intentional exposure of a patient during medical treatment.

For any laser whose radiation emission is potentially hazardous (normally a laser of any class other than Class 1 or Class 2), protective measures may be necessary to ensure that reasonably foreseeable levels of human exposure to laser radiation cannot exceed the maximum permissible exposure (MPE). Wherever reasonably practicable, this should be done by total enclosure of the radiation and the complete elimination of the hazard at its source. Where this is not feasible, the necessary protective measures should be determined on the basis of a risk assessment as discussed in Clause 7. However, the levels of exposure that might arise and the conditions under which hazardous levels of exposure can occur should first be evaluated.

Values of MPE are given for eye and skin exposure in Tables 5, 6 and 7 as functions of the laser emission wavelength and exposure duration. They are discussed in more detail in Clause 5. The International Commission on Non-Ionising Radiation Protection (ICNIRP) develops these values. They are set below known damage thresholds and are based on the best available information. The MPE values should be used as guides in the control of exposure and should not be regarded as precisely defined dividing lines between safe and hazardous levels. Because exposure to laser radiation below the MPE can still be uncomfortable in certain circumstances and may cause secondary hazards (as explained below), exposure should in any case be kept as low as reasonably practicable.

4.2.2 Temporary visual effects

Visible emission from lasers can cause disturbing and potentially dangerous dazzle effects at exposure levels that are well below the maximum permissible exposure (see 4.2.1) and which therefore cause no direct physiological injury. This is especially so with laser classes 2, 2M and 3R (includes laser pointers and low-power alignment lasers). These should not therefore be directed, whether intentionally or unintentionally, at a person's eyes. This can startle and distract the exposed person, and can cause them to lose concentration, with particularly serious consequences if the person is performing a safety-critical task, such as driving or controlling machinery. It can also produce disturbing after-images, generate fear, and induce reactions such as watering eyes and headaches if the person believes that they might have suffered injury as a consequence of exposure. Persistent rubbing of the eyes in response to a perceived injury can also result in painful corneal abrasions.

4.3 Determining the level of laser exposure

4.3.1 The effective exposure

An assessment of laser exposure may be needed in order to determine the boundary of the laser hazard zone, or to specify the level of protection that is necessary (for example, with the use of laser protective eyewear or protective viewing windows).

The level of human exposure arising from a laser product should be determined at the positions at which it is reasonably foreseeable that a person might be located and where the highest levels of exposure can occur. This evaluation should take into account all reasonably foreseeable conditions of direct beam emission and beam reflection.

This maximum anticipated level of exposure is not necessarily the same as that which would arise immediately adjacent to the emission aperture of the laser, although for persons who are in reasonably close proximity to a laser producing a collimated beam it will be.

For CW (continuous wave) lasers, the exposure will normally be expressed in terms of the incident irradiance, specified in units of watts per square metre. With pulsed lasers, both the average irradiance (in watts per square metre) and the radiant exposure due to a single pulse (and specified in joules per square metre) will usually need to be known. In assessing the level of exposure, careful attention must be made to the relevant limiting aperture (see 4.3.2) and where relevant, to the procedures for dealing with large (*extended*) laser sources (see 4.3.3 and 5.4). These considerations can mean that the value of the applicable exposure (called the *effective* exposure) that must be used for comparison with the MPE may not be the same as the exposure that would actually arise.

The main parameters that may be needed for exposure assessment are as follows:

- emission wavelength;
- beam dimensions at laser output;
- beam divergence and position of the beam waist;
- beam profile (power or energy distribution across the beam);
- maximum reasonably foreseeable exposure duration;
- minimum reasonably foreseeable exposure distance;
- angular subtense of apparent source (this is usually only needed for laser arrays and for the assessment of diffuse, i.e. non-specular, beam reflections, in order to determine the relevant exposure parameters and to calculate the value of the correction factor C₆. In the case of single laser sources C₆ normally has the value 1);
- for scanning beams, the scanning characteristics and scan geometry.

In addition, for continuous (CW) emission:

- beam power;

and for pulsed emission:

- pulse energy;
- pulse duration;
- pulse repetition frequency;
- pulse shape and pulse distribution in time (if complex).

Levels of exposure may be determined by physical measurement, or by calculation based on the emission parameters of the laser as specified by the manufacturer.

The profiles of most laser beams are non-uniform, and therefore the irradiance or radiant exposure arising from exposure to the beam will vary across the exposed area (in most cases having a maximum value at the centre of the beam). The MPE relates to the value of the exposure (irradiance or radiant exposure) when averaged over a circular area defined by the relevant limiting aperture, as defined in 4.3.2. For purposes of comparison with the MPE, therefore, an exposure is equivalent to the power (in the case of irradiance) or to the energy (in the case of radiant exposure) that is contained within the specified limiting aperture, divided by the area of the limiting aperture.

Where an exposure covers an area that is much larger than the limiting aperture, the maximum (normally on-axis) value of the irradiance or radiant exposure can be used.

NOTE For circular beams having an approximately Gaussian profile, the on-axis value is equal to the total beam power or energy divided by the area of the beam determined on the basis of its $1/e$ diameter. This area contains 63 % of the total beam power or energy. The $1/e$ diameter is the diameter at which the beam irradiance, radiant exposure or radiant intensity has decreased to $1/e$, or 0,37, of the peak, on-axis value. In many cases, however, the diameter of the beam will be specified by the manufacturer in terms of the $1/e^2$ value. The $1/e^2$ diameter is equal to the $1/e$ diameter multiplied by 1,4.

In other cases a more careful assessment of the total power or energy contained within the relevant limiting aperture may be necessary. For beams that are smaller than the relevant limiting aperture, the effective exposure (for purposes of comparison with the MPE) is the total power or energy of the beam divided by the area of the limiting aperture, not by the actual area of the beam.

4.3.2 Limiting apertures

An appropriate averaging aperture should be used for all measurements and calculations of exposure values. This is referred to as 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 2.

Table 2 – The diameter of the limiting aperture applicable to measurements of irradiance and radiant exposure (t is the exposure duration)

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

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 ocular hazard from an individual pulse of duration no greater than 0,35 s, whereas the 3,5 mm aperture is applied for evaluating the MPE applicable to exposures longer than 10 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.

4.3.3 Angle of acceptance for the assessment of exposure from extended sources

The majority of single lasers represent “small” sources, since the angular subtense of the apparent source is less than $\alpha_{\min}$ (1,5 mrad). Where the emission from such sources is within the retinal hazard region (i.e. between 400 nm and 1 400 nm), it can be focused by the eye to form an effective point image on the retina. This is not possible with larger apparent sources (often called *extended* sources), which, therefore, for a given level of exposure at the surface the eye, may be less hazardous. Extended-source exposure conditions may be applicable to diffuse reflections, laser arrays or laser products employing a diffuser, when these are viewed at a sufficiently close distance.

When determining the level of the effective exposure arising from an extended laser source (that is, any source subtending more than 1,5 mrad at the position at which the exposure is being assessed), the following angles of acceptance should be used. Any contribution to the exposure that is due to the source's emission arising from outside the angle of acceptance should be excluded from the assessment of the effective exposure.

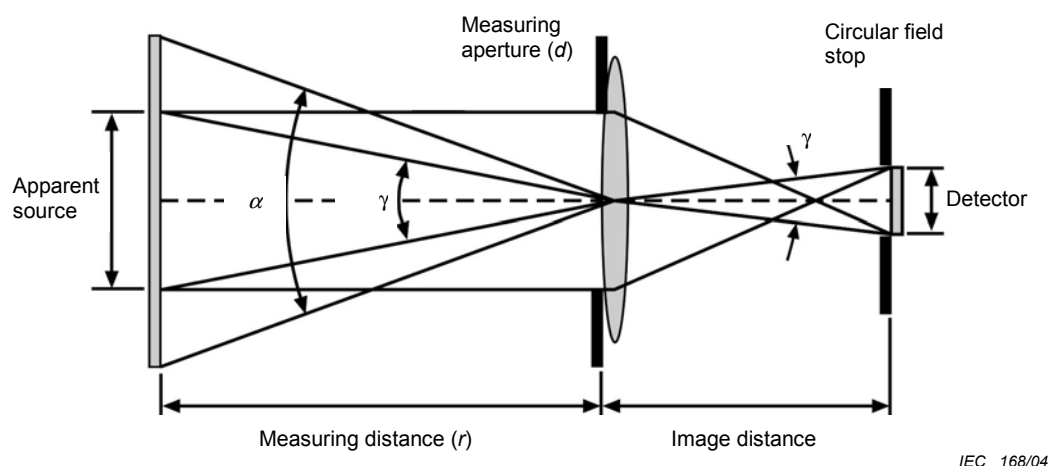
The angular subtense of the apparent source is measured at the distance at which the exposure is being assessed, but not at a distance less than 100 mm. (The angular size of a source should not be confused with the divergence of its emission. To take the sun as an example, its angular size as viewed from the earth is only $0,5^\circ$, but the divergence of its emission is 360° .)

a) For the determination of the level of exposure to be evaluated against the photochemical MPEs in Table 6 (400 nm to 600 nm), the limiting angle of acceptance γ_p is

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

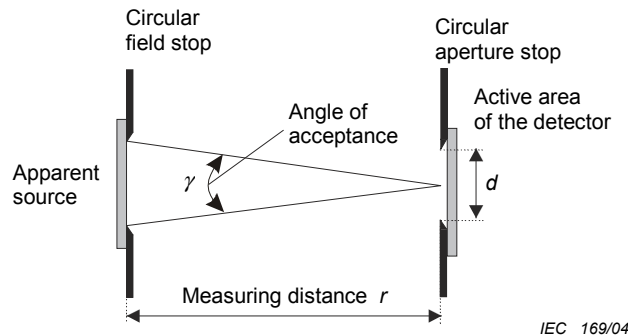
If the angular subtense of the source α is larger than the specified limiting angle of acceptance γ_p , the angle of acceptance should not be larger than the values specified for γ_p . If the angular subtense α of the source is smaller than the specified limiting angle of acceptance γ_p , the angle of acceptance should fully encompass the source under consideration but otherwise need 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 Figure 2.



NOTE Above is an example of a measurement set-up providing a well-defined angle of acceptance by using a lens to image the apparent source onto the detector. This arrangement can be used where the apparent source is not directly accessible.

Figure 2a – Measurement set-up using a lens



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NOTE A measurement set-up using an aperture located at the apparent source to define the angle of acceptance of the detector.

Figure 2b – Direct measurement set-up

Figure 2 – Measurement set-ups

- b) For the determination of the level of exposure to be evaluated against all MPEs given in Table 6 other than the retinal photochemical hazard limit, the angle of acceptance should 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 should not be larger than $\alpha_{\max}$ (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 $\alpha_{\min} \leq \gamma \leq \alpha_{\max}$.

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 $\alpha_{\max}$ or less than $\alpha_{\min}$ should be limited to $\alpha_{\max}$ or $\alpha_{\min}$ respectively, prior to calculating the mean. The retinal photochemical MPEs do not depend on the angular subtense of the source, and the exposure is determined using the angle of acceptance specified above in 4.3.3(a).

4.3.4 Use of binoculars

If a laser source is viewed through binoculars, then the increase in the effective exposure at the surface of the eye will be the smaller of either M^2 or $(D/d)^2$, where M is the angular magnification of the binoculars, D is the diameter of the objective (i.e. outer) lenses and d is the diameter of the relevant limiting aperture. (Binoculars are normally specified in the form $M \times D$, e.g., 7 x 50.) Allowance can be made for transmission losses through the binoculars at the laser wavelength if this is known. Typical transmission percentages for binoculars are given below:

Wavelength	% Transmission
0,18-0,302 μm	<2%
0,302-0,4 μm	70%
0,4-0,7 μm	90%
0,7-2,8 μm	70%
2,8-10 ³ μm	<2%

The angular subtense of an extended source viewed through the binoculars will be increased by a factor M .

5 Determining the maximum permissible exposure (MPE)

5.1 General remarks

Levels of maximum permissible exposure, which are based on values developed by the International Commission on Non-Ionising Radiation Protection (ICNIRP), are given in Tables 5, 6 and 7 as functions of the emission wavelength and exposure duration. These tables should be used in conjunction with the correction factors given in Table 8.

Table 5 defines the MPE for the eye under conditions of direct exposure to a single laser beam (and in all other cases where the apparent angular subtense of the laser source does not exceed 1,5 mrad, see 4.3.3). For exposure of the eye to laser radiation at wavelengths between 400 nm and 1 400 nm (the retinal hazard region) to larger apparent sources than would be the case for the direct viewing of a single laser beam (that is, for certain multiple or extended sources that subtend an angle at the eye greater than 1,5 mrad), a relaxation (increase) in the MPE is possible. This is because the eye cannot focus such non-point sources onto a small spot on the retina, and therefore the maximum safe power or energy entering the eye is larger. These relaxed MPEs are given in Table 6.

Table 7 specifies values of the MPE for the skin.

The exposure duration used in determining the MPE from Tables 5, 6 and 7 should be based on the maximum duration of accidental exposure that could reasonably be expected to occur, taking into account the wavelength of laser emission and the conditions under which the laser might be used. Under worst-case conditions of accidental exposure, 100 s may be used as the maximum duration of exposure for laser radiation at wavelengths above 400 nm, and 30 000 s for wavelengths below 400 nm where longer-term photochemical effects may be initiated. This longer time-base is applicable in circumstances where repeated or prolonged exposure to ultraviolet radiation could occur without an immediate apparent effect, but is clearly not realistic in the case of direct accidental exposure to a high-power ultraviolet laser beam where immediate and obvious injury would be caused. For accidental exposure to visible laser radiation (400 nm – 700 nm) where purposeful staring is not intended or anticipated, the aversion response time of 0,25 s may be used.

Further consideration of the exposure duration is included in the discussion of risk assessment given in 7.3.

5.2 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 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 are 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 5, 6, and 7 for a single pulse of exposure duration T . (T is the duration used in the assessment of exposure as discussed in 4.1.)
- 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 that was used to determine N . Every averaged pulse exposure is to be compared to the reduced MPE_{train} as specified below:

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

where

MPE_{train} is the MPE for any single pulse in the pulse train;

MPE_{single} is the MPE for a single pulse;

C_5 is the $N^{-1/4}$

N is the 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.

If pulses of variable amplitude are used, the assessment is made for pulses of each amplitude separately using requirement a), 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 Table 8) and 10 s for longer wavelengths. If multiple pulses appear within the period of T_i (see Table 3) 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 2 C_5 is only applicable to individual pulse durations shorter than 0,25 s.

NOTE 3 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 4 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 time 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 .

Table 3 – Duration T_i below which pulse groups are summed up

Wavelength	T_i
$400 \text{ nm} \leq \lambda < 1\,050 \text{ nm}$	$18 \times 10^{-6} \text{ s}$
$1\,050 \text{ nm} \leq \lambda < 1\,400 \text{ nm}$	$50 \times 10^{-6} \text{ s}$
$1\,400 \text{ nm} \leq \lambda < 1\,500 \text{ nm}$	10^{-3} s
$1\,500 \text{ nm} \leq \lambda < 1\,800 \text{ nm}$	10 s
$1\,800 \text{ nm} \leq \lambda < 2\,600 \text{ nm}$	10^{-3} s
$2\,600 \text{ nm} \leq \lambda \leq 10^6 \text{ nm}$	10^{-7} s

5.3 Multiple wavelengths

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 5, 6 and 7 provided that:

- the pulse width or exposure duration are within one order of magnitude, and
- the spectral regions are shown as additive by the symbols (O) for ocular and (S) for skin exposure in the matrix of Table 4.

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