



BSI Standards Publication

Safety of laser products

Part 14: A user's guide

National foreword

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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TECHNICAL REPORT



Safety of laser products – Part 14: A user's guide

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ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –**Part 14: A user's guide****FOREWORD**

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IEC TR 60825-14 has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2004. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) incorporates changes made in IEC 60825-1:2014;
- b) adds information to users of laser equipment on administrative controls to ensure safety in the workplace, including the training and appointment of people to specific laser safety management roles;
- c) updates an approach to risk assessment;
- d) includes updated guidance on the management of incidents and accidents;
- e) includes updated guidance on medical surveillance for laser workers;
- f) includes revised examples of calculations.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
76/661/DTR	76/693/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts of the IEC 60825 series, published under the general title *Safety of laser products*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

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INTRODUCTION

To help in the use of this document, 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 4.
- The meaning of the laser product classes and the assessment of laser exposure are covered in Clause 5.
- 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 6.
- Associated laser hazards (that is, hazards other than those of eye or skin exposure to the emitted laser beam) are covered in Clause 7.
- A three-stage process for evaluating risk (arising from both the laser radiation hazards discussed in Clause 5 and Clause 6, and the associated laser hazards discussed in Clause 7) is covered in Clause 8. These three stages are
 - 1) the identification of 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 9.
- The need to ensure the continuation over time of safe laser operation is covered in Clause 10.
- The reporting of laser-related hazardous incidents and the investigation of accidents is covered in Clause 11 and Clause 12.
- The role of medical surveillance (eye examinations) is covered in Clause 13.
- 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.

SAFETY OF LASER PRODUCTS –

Part 14: A user's guide

1 Scope

This document provides guidance on best practices 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 that is capable of emitting optical radiation produced by a process of stimulated emission.

Class 1 laser products normally pose no beam hazard and Class 2 and Class 3R laser products present only a minimal beam hazard. With these products, it is normally sufficient to follow the warnings on the product labels and the manufacturer's instructions for safe use. It is unlikely that further protective measures as described in this document will be necessary.

This document emphasizes evaluation of the risk from higher power lasers, but the users of the lower power lasers can benefit from the information provided

This document 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 document is intended to help laser users and their employers to understand the general principles of safety management, to identify the hazards that can be present, to assess the risks of harm that can arise, and to set up and maintain appropriate control measures. Although the guidance given in this document is aimed principally at organizations (whether private, corporate or public), where systems of safety management would be expected to be in place, it can be applied by anyone using lasers.

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 are at risk of harm. Specific requirements for certain laser applications are given in other documents in the IEC 60825 series.

The terms "reasonably foreseeable" and "reasonably foreseen" 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 occurrences might be "reasonably foreseen", 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 includes persons having responsibility for safety in addition to those who actually work with or operate laser equipment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60825-1:2014 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

control measure

precaution adopted to reduce the risk of harm occurring

Note 1 to entry: Control measures include engineering controls (safety features incorporated into the laser equipment), administrative controls (documented policies, operating procedures, safety training, etc.) and personnel protection (safety equipment including eye protection that is worn by individuals).

3.1.2

laser equipment

laser product

assembly that is a laser or contains a laser

3.1.3

optical density

OD

$D(\lambda)$

logarithm to base ten of the reciprocal of the transmittance τ

$$D(\lambda) = -\log_{10} \tau$$

3.1.4

protective enclosure

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

3.2 Symbols

Symbol	Unit	Definition
a	m	Diameter of the emergent laser beam.
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.
$\alpha_{\min}$	rad	Minimum angle subtended by a source for which the extended source criterion applies ($\alpha_{\min} = 1,5$ mrad).
$\alpha_{\max}$	rad	The value of angular subtense of the apparent source above which the MPEs are independent of the source size ($\alpha_{\max} = 5$ mrad to 100 mrad, see Table 10).
$C_1, C_2, \dots, C_7$	no units	Correction factors (see Table 9).
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.
$D(\lambda)$	no units	Optical (transmittance) density defined as the logarithm to base 10 of the reciprocal of the transmittance (see also IEC 845-04-66).

Symbol	Unit	Definition
D_e	m	Diameter of the exit pupil of an optical system.
D_o	m	Diameter of the objective of an optical system.
η	no units	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	no units	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 E	$J \cdot m^{-2}$ $W \cdot m^{-2}$	Radiant exposure or irradiance at a specified distance, r , from the apparent source.
H_o E_o	$J \cdot m^{-2}$ $W \cdot m^{-2}$	Emergent beam radiant exposure or irradiance at zero distance from the apparent source.
k	no units	Irradiance averaging factor with values ranging from $k = 1$ for beams having Gaussian profiles to $k = 2,5$ for beams of unknown mode structure.
L_p	$J \cdot m^{-2} \cdot sr^{-1}$	Integrated radiance of an extended source.
λ	nm	Wavelength of laser radiation.
M	no units	Magnification of an optical instrument.
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	no units	Number of pulses contained within an exposure duration.
NA	no units	Numerical aperture of a laser source.
NA_m	no units	Numerical aperture of a microscope objective
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.
R_{NOH}	m	Nominal ocular hazard distance.
$R_{NOH,E}$	m	Extended nominal ocular hazard distance.
φ	rad	Divergence angle of an emergent laser beam
π	no units	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 Table 10).

4 Administrative policies

4.1 Safety responsibilities

Safety responsibilities may be specified by national or local regulations. 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 (environment) 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 needs to 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 organization'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, Class 1C, Class 2, or Class 3R 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, 5.1.3 concerning embedded lasers and 5.2.2 concerning transient visual effects.

4.2 Competent Person

Where the employer or laser user is not able, without assistance, to properly determine the necessary safety arrangements and protective measures for eliminating or minimizing 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, relating particularly to the specific technical area within which advice is being sought, 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 (often termed the Laser Protection Adviser (4.5.1) when considering laser beam hazards) need not be an employee of the organization 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.

4.3 Laser Safety Officer

A Laser Safety Officer (LSO) should be appointed in organizations 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 5.1.3), 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 7.)

The Laser Safety Officer should be authorized to act on behalf of the employer and take responsibility, on behalf of that 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 the technical understanding, competence and capability that are necessary to perform the duties required. Appropriate training and sufficient resources should be provided to support the Laser Safety Officer in this role.

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 organization concerned, but are likely to include as a minimum:

- being aware of and, if appropriate, maintaining records of all potentially-hazardous laser products (including the classifications, specifications, and purposes of the laser products; the locations of the laser products; and any special requirements or restrictions relating to their uses);
- responsibility for monitoring compliance with the organization'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 authorize, 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 4.2) has been appointed and that person is an employee of the organization concerned (often desirable in organizations having extensive and varied laser use), then the Competent Person may also be the Laser Safety Officer.

In large organizations where there is extensive laser use or in higher risk applications, suitable employees may be appointed to assist the Laser Safety Officer by being tasked to manage day to day safety of a particular activity or by being given more local responsibility for specific laser areas. In such circumstances, regular liaison should be maintained between all those involved to ensure the consistent and effective management of laser safety throughout the organization.

4.4 Information and training

All employees should, where relevant, be made aware of any hazards (including associated hazards; see Clause 7) 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 3 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, the following:

- a) the organization'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 9.4.5);

- 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.

4.5 Levels of competence

4.5.1 Laser Protection Adviser

Where an employer is not competent to undertake without assistance the necessary duties with regard to laser safety, a Competent Person, having sufficient skill, knowledge and experience, should be appointed to advise the employer in these matters and to provide assistance in the establishment of the organization's laser safety policy and in the implementation of the required arrangements. Such a person, called a Laser Protection Adviser, may be an employee of the organization concerned or an external adviser.

The employer should ensure that all relevant information relating to the use or intended use of the laser equipment is made available to the Laser Protection Adviser, and that the Laser Protection Adviser is given sufficient time and resources to enable him or her to undertake the necessary tasks effectively, having regard to the size of the organization, the risks to which employees may be exposed, and the distribution of those risks throughout the organization.

Many larger organizations undertaking extensive and varied laser work may find it convenient to retain professional laser safety skills in-house and to combine the role of the Laser Safety Officer with that of the Laser Protection Adviser in one employee.

In other circumstances, however, the Laser Safety Officer need not be the Laser Protection Adviser, since it is neither necessary nor appropriate for a high level of expertise in laser safety to be retained in-house where such expertise cannot be utilized on a regular basis. In such cases the employer, or on their behalf the Laser Safety Officer, should seek the guidance of an external Laser Protection Adviser whenever necessary.

Any person acting as a Laser Protection Adviser should have sufficient knowledge, understanding, competence and experience in relevant matters of laser safety, particularly with regard to the following:

- the provisions and applicability of relevant safety standards and national regulations;
- the type of laser equipment in use;
- the particular application or working environment concerned;
- the hazards that may be present;
- hazard evaluation and risk assessment procedures;
- safety management;
- the selection, specification and proper use of hazard controls;
- the safety training requirements of relevant personnel;
- the drafting of safe working procedures.

4.5.2 Laser Safety Officer

Every organization within which laser equipment of Class 3B or Class 4 is in use should appoint an internal Laser Safety Officer to take administrative responsibility on behalf of the employer for overseeing laser safety. Certain lower class embedded laser products contain lasers Class 3B or Class 4 emission levels that may produce hazardous accessible emissions under some conditions of use, e.g. during servicing, and could therefore also necessitate the appointment of a Laser Safety Officer. The appointment of a Laser Safety Officer is also

recommended where Class 1M or 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. In some instances, it may be appropriate to appoint a Laser Safety Officer where lower power (3R and below) visible laser beams are being used in a high-risk environment, e.g. roadside construction sites, where persons are performing safety critical tasks, and there is the potential for interference with vision.

The Laser Safety Officer should ensure that adequate controls for minimizing health risks arising from the use of laser equipment are in place, that regular monitoring of laser hazards and of the effectiveness of control measures is carried out, and that records of such monitoring are maintained.

Overall responsibility for laser safety remains with the employer, who should ensure that the person appointed as the Laser Safety Officer has the capability, knowledge and understanding, as well the resources needed, to undertake these tasks effectively. Within the limits of the mandate from the employer the Laser Safety Officer bears the responsibility for the safety control actions, both engineering and administrative.

Within large organizations having extensive laser use, a more continuous (day to day) laser safety presence is beneficial, so it can often be helpful to appoint area or departmental laser safety representatives to assist the Laser Safety Officer and to provide more local support to laser users.

The standard of competence necessary for a Laser Safety Officer is that they should:

- know that optical radiation encompasses visible light and invisible infrared and ultraviolet radiation, that it is designated in terms of wavelength, and that it differs from ionizing radiation;
- know the basic characteristics (spatial, spectral and temporal) of laser emission;
- understand the appropriate quantities and units in which laser emission is specified;
- know of the existence of relevant laser safety standards and national regulations affecting laser use;
- understand the concept of laser hazard Classes 1, 1C, 1M, 2, 2M, 3R, 3B and 4, and the meaning of laser warning labels;
- know the type(s) of laser equipment in use within the organization concerned and understand its intended purpose;
- know the waveband(s) and wavelength(s) of emission of the laser equipment in use;
- know the tissue(s) at risk from laser beam exposure, and in the case of laser emission within the retinal hazard region (wavelengths between 400 nm and 1 400 nm) understand the focusing effects of the eye;
- appreciate the severity of harm that can occur from laser beam exposure;
- know the approximate area around the laser(s) within which hazardous exposure levels may arise under different circumstances of use;
- understand the nature and extent of other hazards that may arise from the use of the laser equipment, including
 - mechanical hazards,
 - electrical hazards,
 - noise and vibration hazards,
 - thermal hazards,
 - fire and explosion hazards,
 - chemical hazards;
 - biological hazards including laser fume or plume, and

- radiation hazards, in addition to those due to laser emission;
- understand the control procedures that are necessary to eliminate the risk of harm occurring or to reduce this risk to an acceptable level, including the proper use of warning signs and controlled areas;
- understand the essential requirements of occupational health and safety and the general principles of good safety management;
- understand the need to establish, document and implement safe working procedures (covering normal operation, adjustment work, and the occurrence of unplanned events, including accidents);
- have sufficient technical understanding and management ability to be able to take administrative responsibility, on behalf of the employer, for overseeing, regular monitoring, and the continuous control of laser hazards within the organization, having due regard to the type(s) of laser(s) in use, the specific nature of the laser application(s), the people involved in the work, and the kind(s) of working environment(s) concerned;
- know how to respond to laser-related accidents and to other incidents where safety could be compromised;
- know how to seek, and be able to act on, the specialist advice of a Laser Protection Adviser whenever necessary.

4.5.3 Laser Safety Supervisor

One or more Laser Safety Supervisors may be appointed to manage the day-to-day safe operation of the laser(s). They would be expected to have a higher level of competency than the laser user but have access to the Laser Safety Officer and/or Laser Safety Adviser when necessary. The duties of the Laser Safety Supervisor should be agreed in writing but are likely to include ensuring that any safety systems are in place and procedures complied with. The Laser Safety Supervisor is likely to be directly involved with the laser work.

4.5.4 Laser user

Those who use, work with, or who are placed in control of laser equipment of Class 1M, 2M, 3R, 3B or 4 should be sufficiently competent in the operation and use of the equipment, and in addition should:

- understand the general nature of laser radiation,
- know the health hazards that can arise from the use of the laser equipment, the tissues of the body which are at risk, and the severity of harm which can result,
- understand the meaning of the warning labels appropriate to the class(es) of laser being used,
- understand the proper use of hazard control procedures including, where appropriate, the need for personal protection,
- be aware of the need for any additional precautions that may be necessary when undertaking nonroutine activities, such as adjustment work,
- be familiar with the organization's procedures and policy governing laser use, including emergency action and accident reporting procedures.

4.5.5 Awareness for other persons

Persons who are not themselves involved in using or working with laser equipment, but who nevertheless have some responsibility for laser equipment of Class 1M, 2M, 3R, 3B or 4, for those who use it, or for general health and safety matters within the organization, should have some understanding of the general issues of laser safety. Such persons could include, for example, supervisors, managers, safety officers, occupational health and safety staff, auxiliary staff required to enter a laser hazard area as part of their duties, e.g. cleaners, security, general maintenance, etc., and employee representatives. They should appreciate in general terms the extent and function of laser equipment within the organization, and in addition should:

- understand the general nature of laser radiation and laser radiation hazards,
- have a knowledge of the classification scheme for lasers and the meaning of laser warning signs,
- appreciate the extent of laser use within the organization, and its intended purpose,
- be familiar with the organization's policies regarding laser safety,
- know the particular hazards arising from the use of laser equipment within the organization and be aware of the control measures that are in place,
- know restrictions on access to any laser controlled area and the meaning of access restriction signs,
- have good knowledge of the safety infrastructure.

4.6 Training requirements

Training in laser safety, and also in associated issues of occupational safety and health, should be given to employees whenever necessary in order to provide them with sufficient skills, knowledge and understanding to ensure that laser equipment is safely used and that the organization's laser safety policies are effectively and continuously implemented.

Training should be suitable, sufficient and comprehensible, taking into account the experience, capabilities and educational level of the employees being trained. Refresher training should also be given at reasonable intervals to ensure that an adequate level of safety awareness and competence is maintained.

Any suitable method of training can be used, and may be by means of one, or a combination of any, of the following:

- a short course given internally from the organization's own resources;
- a short course given internally by an external trainer;
- attendance at an externally-run off-site course;
- the use of computer-aided learning packages;
- self-teaching through books, etc. and remote learning by correspondence;
- work experience and informal one-to-one training.

In the case of a person seeking to become a Laser Protection Adviser, a single short course or period of study is not normally sufficient to develop adequate competence for this role. A high-level of capability combined with considerable experience in the relevant area of laser application is needed.

4.7 Accreditation

There are currently no internationally recognized schemes for accrediting laser safety courses, or for approving individuals and organizations able to provide training services or safety advice. In determining the suitability of particular training courses or training providers for Laser Protection Advisers, employers should use their own judgement, using this document as a guide, but could also take account of any recommendations given by a third party. Personnel need to be qualified, competent and current for the agreed duties.

NOTE National certification or accreditation schemes are available in some countries.

Trainers should have knowledge exceeding the level of training being taught, e.g. Laser Safety Officers are unlikely be suitably qualified to train equivalent Laser Safety Officers until they have experience or a higher level of skill than the role they are training.

5 Laser radiation hazards

5.1 Laser products

5.1.1 Laser product classification

The class of a laser product gives a broad 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 5.1.2). In addition, it should be recognized that some or all of the original safety features of the incorporated laser product, including labelling, may be inoperative, unusable or inaccessible. Where necessary to ensure safe operation, these safety features should be replicated or replaced.

5.1.2 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, including reasonably foreseeable single fault conditions. Associated hazards (also referred to as non-beam hazards) (see Clause 7) that may also be present during use of the laser do not affect the laser classification. During the maintenance or servicing of embedded laser products, access may be gained to higher levels of radiation than is indicated by the class of the product.

NOTE 1 See IEC 60825-1: 2014, 6.2.1

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 all reasonably foreseeable conditions of operation, 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 5.1.3). 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 if the emitted laser beam is modified, such as by using external optics to reduce the size or divergence of the emitted beam in a manner that could increase its hazard, then the protection requirements of the appropriate higher class apply.)

b) Class 1C

Laser products that are intended to be used in direct contact with the skin of a person. Ocular hazard is prevented by one or more engineering means which only permit exposure when the applicator is in contact with the skin. The MPE for the skin may be exceeded, depending on the intended purpose of the product.

Protection requirements for Class 1C: These products should have adequate engineering controls to protect the eyes from laser radiation. However, modification or defeat of safety features may result in hazardous exposure to laser radiation. Repeated exposure of the same area of the skin may cause injury.

c) 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. Hazardous exposure can also occur if the dimensions of the laser beam 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 or telescopes, but not spectacles or contact lenses). Avoid placing optical devices in the emitted beam that could decrease the beam diameter. 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.

NOTE 2 In the case of optical fibre communication systems assessed under IEC 60825-2 using hazard levels instead of the product classes specified in IEC 60825-1, an ocular hazard might be introduced in the case of hazard level 1M by the use of magnifiers to view the fibre end face.

d) 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. Laser beams from Class 2 laser products may cause distraction, dazzle, flash blindness or after images, especially under low ambient light levels.

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.

e) 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. Hazardous exposure can also occur if the dimensions of the laser beam are reduced by the use of optical components in the beam path. Laser beams from Class 2M laser products may cause distraction, dazzle, flash blindness or after images, especially under low ambient light levels.

Protection requirements for Class 2M: Avoid the use of magnifying viewing aids or instruments (such as binoculars or telescopes, but not spectacles or contact lenses). Avoid placing optical devices in the emitted beam that could decrease the beam diameter. Avoid staring into the beam (i.e. deliberate viewing of the laser source) or pointing the beam at other people.

NOTE 3 In the case of optical fibre communication systems assessed under IEC 60825-2 using hazard levels instead of the product classes specified in IEC 60825-1, the ocular hazard in the case of hazard level 2M might be increased by the use of magnifiers to view the fibre end face such that the aversion response cannot provide sufficient protection.

f) 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. Laser beams within the wavelength range 400 nm to 700 nm from Class 3R laser products may cause distraction, dazzle, flash blindness or after images, especially under low ambient light levels. The natural aversion response for exposure to bright light for the case of visible radiation and the response to heating of the cornea for far infrared radiation reduce the risk of eye injury.

Protection requirements for Class 3R: Prevent direct eye exposure to the beam or pointing the beam at other people. Consider conducting a risk assessment that takes into account the actual use and the operational environment, particularly in low ambient light conditions.

g) Class 3B

Laser products having a level of accessible emission, which can be harmful to the eyes for any direct intrabeam exposure (including specular reflection), even for exposure durations shorter than the aversion response time, 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.

h) 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 1C, 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 Class 1 and Class 1M may also carry labels, but at the discretion of the manufacturer, the required wording can instead be included in the printed user information supplied with the product. 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, 1C, 1M, 2, 2M or 3R), are used in a way where the accessible emissions do not exceed 3R (e.g. Class 1M or 2M cannot be viewed through telescopic optics) and are used in an implicitly low risk environment, 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 summarized 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.

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, or reasonably foreseeable misuse.) 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 9.5).
1C	No special precautions are required to protect the eye during normal operation because the product should have effective engineering controls. Repeated exposure of the same site on the skin is not advised. Products should have effective engineering controls to prevent use of the applicator on the face where the eye may be at risk of exposure to optical radiation in excess of the appropriate maximum permissible exposure level.
1M	Prevent direct viewing of the laser source through magnifying viewing instruments, such as binoculars or telescopes, unless these incorporate adequate levels of protection.^a Prevent the use of any external optics that could decrease the diameter. 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 9.5).
2	Do not stare into the beam. Do not look into the laser or 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. 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 9.5).
2M	Do not stare into the beam. Do not look into the laser or 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 or telescopes, unless these incorporate adequate levels of protection.^a Prevent the use of any external optics that could decrease the beam diameter. 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 9.5).
3R	Prevent direct eye exposure to the beam. Do not look into the laser or direct the beam at other people or into areas where other people unconnected with the laser work may be present. Ensure the beam is always terminated at a suitable non-specular (i.e. non mirror-like) surface. 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 9.5).
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. Ensure the beam is always terminated at a suitable non-specular (i.e. non mirror-like) surface. Where reasonably practicable, use engineering means, as specified in IEC 60825-1, to reduce the effective class of the laser system 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.	

5.1.3 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. However, Class 2 and Class 3R products may also contain lasers of a higher class. 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 9.5.

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 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.

5.1.4 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 optical fibre communication system may be assigned different hazard levels. (This is in contrast to the class of a laser product, which is based on the highest level of accessible emission that could arise during normal operation from any part of the product. The class allocated applies to the complete product.)

Safety requirements for the use of optical fibres to deliver laser radiation in applications other than communication systems, for example in materials processing applications, need to consider the risk of the laser radiation becoming accessible and how such risk can be managed.

5.1.5 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, or when spectators are prevented from exposure to levels exceeding the applicable maximum permissible exposure (MPE).

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

5.1.6 Consumer laser products

Laser products intended to be used by people who are unlikely to have been trained in safe laser use should normally be restricted to Class 1, Class 1C or Class 2. Class 1M, Class 2M and Class 3R lasers may be incorporated into consumer products where the application is justified and where adequate instructions for safe use are supplied with the product. Such instructions should be appropriate for the intended user. Class 3B and Class 4 laser products are not recommended for use as consumer products.

5.2 Exposure to laser radiation

5.2.1 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 5.3), and then to relate this to the maximum permissible exposure (the MPE, outlined below and explained in more detail in Clause 6).

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 8. 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 Table 4 to Table 8 as functions of the laser emission wavelength and exposure duration. They are discussed in more detail in Clause 6. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) develops these values. They are set below known damage thresholds and are based on the best available information. The MPE can be regarded as the level above which there should be safety control. The MPE should not be used as a guide above which one would necessarily expect an injury. 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.

5.2.2 Transient visual effects

The classification of a laser product relates to the relative risk of permanent tissue damage and the potential for causing injury. But even with laser products in Classes 1 and 2, where the risk of injury is very low or non-existent, visual discomfort such as disability and discomfort glare ("dazzle"), and flash-blindness or after images, can occur from direct viewing of laser radiation in the visible spectrum. These transient visual effects can give rise to secondary risks, particularly under low ambient light conditions. They may therefore have indirect implications on general safety, resulting from temporary disturbance of vision or from startle reactions. Such visual disturbances could be of particular concern if experienced while performing safety-critical operations such as working with machines or at height, with high voltages or driving/flying. In

some jurisdictions the misuse of intense, visible (e.g. green) laser pointers has been banned (or prevented by legal action).

Such sudden and unexpected visual disturbances can also generate fear and can 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 may result in painful corneal abrasions.

5.3 Determining the level of laser exposure

5.3.1 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 needs to be paid to the relevant limiting aperture (see 5.3.2) and, where relevant, to the procedures for dealing with large (extended) laser sources (see 5.3.3 and 6.4). These considerations can mean that the value of the applicable exposure (called the effective exposure) that needs to 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 C_6 . In the case of single laser sources, C_6 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 5.3.2. 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 of the irradiance or radiant exposure 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 d_{63} 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.

5.3.2 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 time of the relevant exposure, either pulse duration or total exposure)

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 adjusted to take into account smaller pupil diameters.

5.3.3 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 of 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 an angle 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 subtense of a source should not be confused with the divergence of its emission. To take the sun as an example, its angular subtense as viewed from earth is only 8,7 mrad (0,5°), but the divergence of its emission is 2π rad (360°).

a) For the determination of the level of exposure to be evaluated against the photochemical MPEs in Table 5 (400 nm to 600 nm), the limiting angle of acceptance γ_{ph} is

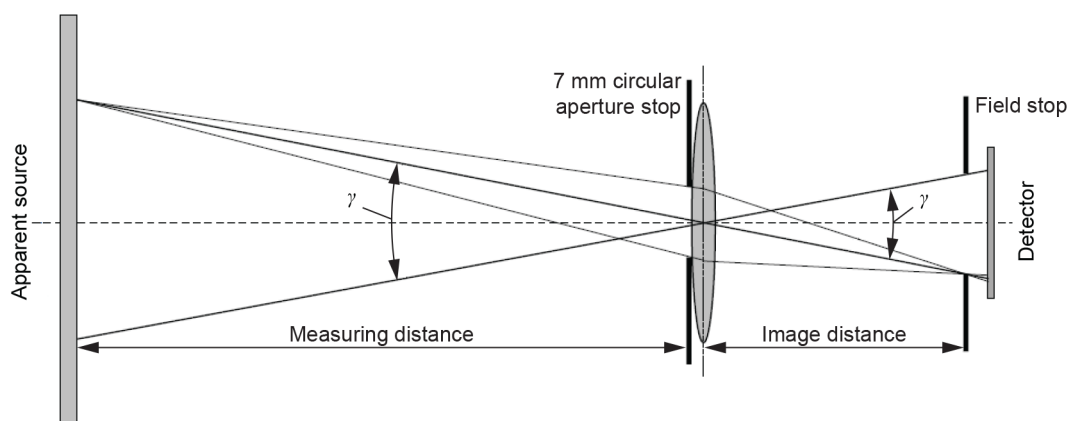
- for $10 \text{ s} < t \leq 100 \text{ s}$: $\gamma_{\text{ph}} = 11 \text{ mrad}$
- for $100 \text{ s} < t \leq 10^4 \text{ s}$: $\gamma_{\text{ph}} = 1,1 t^{0,5} \text{ mrad}$
- for $10^4 \text{ s} < t \leq 3 \times 10^4 \text{ s}$: $\gamma_{\text{ph}} = 110 \text{ mrad}$

If the angular subtense of the source is larger than the specified limiting angle of acceptance γ_{ph} , the angle of acceptance should not be larger than the values specified for γ_{ph} . If the angular subtense of the source is smaller than the specified limiting angle of acceptance γ_{ph} , 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_{ph}).

NOTE For measurements of single small sources, where the angular subtense of the source is smaller than γ_{ph} , 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 1a and 1b. For measurements of extended sources where the angular subtense of the source is larger than γ_{ph} using an angle of acceptance that is larger than the source results in an over-restrictive exposure level, but can be used as a simplified assessment.

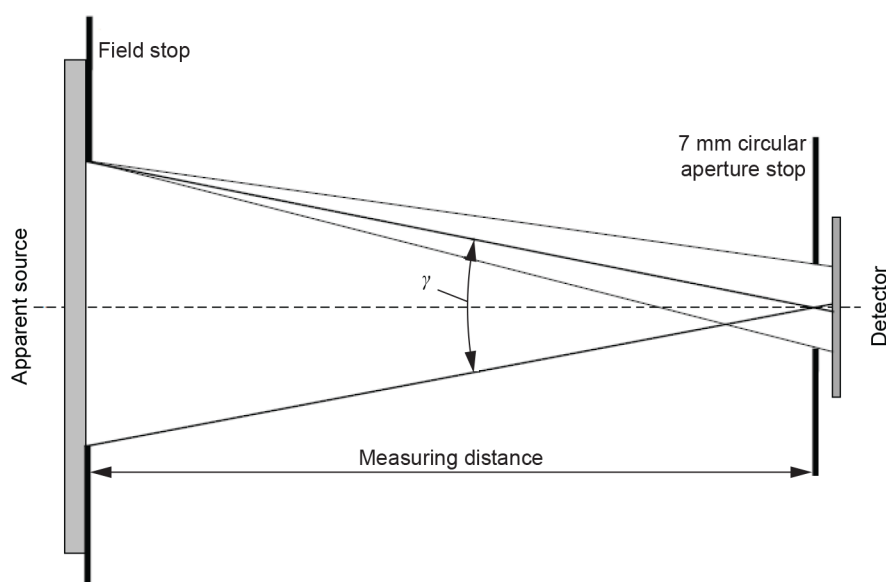
Figure 1a is an example of a measurement set-up providing a well-defined angle of acceptance by using a lens to image the apparent source onto the field stop in front of the detector. This arrangement can be used where the apparent source is not directly accessible.

Figure 1b is an example of a measurement set-up providing a well-defined angle of acceptance by placing the field stop at the source. This arrangement can be used where the source is directly accessible.



IEC

Figure 1a – Measurement set-up using a lens to image the apparent source onto a field stop



IEC

Figure 1b – Direct measurement set-up where the field stop is placed at the source

Figure 1 – Measurement set-ups to achieve a well-defined angle of acceptance

- b) For the determination of the level of exposure to be evaluated against all MPEs given in Table 5 other than the retinal photochemical hazard limit, the angle of acceptance should fully encompass the source under consideration (i.e. the angle of acceptance should be at least as large as the angular subtense of the source). 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 or is for other reasons analysed as extended apparent source, the angle of acceptance should 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 in 5.3.3 a).

5.3.4 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 $M \times D$, where D is expressed in millimetres, e.g. 7×50 .) 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 in Table 3.

Table 3 – Typical transmission percentages for binoculars

Wavelength	Transmission
160 nm to 302,5 nm	< 2 %
302,5 nm to 400 nm	70 %
400 nm to 700 nm	90 %
700 nm to 2 800 nm	70 %
2 800 nm to 10^6 nm	< 2 %

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

6 Determining the maximum permissible exposure (MPE)

6.1 General remarks

Levels of maximum permissible exposure, which are based on values developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), are given in Table 4 to Table 8 as functions of the emission wavelength and exposure duration, as measured through the limiting aperture. These tables should be used in conjunction with the correction factors given in Table 9. The MPE applies to the effective exposure obtained by averaging over the area of the relevant limiting aperture as explained in 5.3.1 and 5.3.2.

Table 4 defines the MPE in terms of the irradiance or radiant exposure at the front surface of 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 5.3.3). 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 5. Table 6 and Table 7 contain the MPEs from Table 4 and Table 5 expressed in energy or power. Dual MPEs are applicable for ocular exposure to wavelengths between 1 200 nm and 1 400 nm: reference may need to be made to Table 8 for the skin MPE to ensure that the anterior elements of the eye are not at risk.

Table 8 specifies values of the MPE for the skin. Table 9 specifies correction factors and breakpoints to be used with the MPE tables.

The exposure duration used in determining the MPE from Table 4 to Table 8 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.

longer (30 000 s) exposure time 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 to 700 nm) where purposeful staring is not intended or anticipated, the aversion response time of 0,25 s may be used.

Exposures from several wavelengths should be assumed to have an additive effect provided that the spectral regions are shown as additive by the symbols (O) for ocular and (S) for skin exposure in the matrix of Table 11 (see 6.3). Where the wavelengths radiated are not shown as additive, the hazards should be assessed separately.

Further consideration of the exposure duration is included in the discussion of risk assessment given in 8.3.4.4.

Table 4 – Maximum permissible exposure (MPE) at the cornea for small sources expressed as irradiance or radiant exposure^{a,b}

Wavelength λ nm	Exposure time, t s							
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 5×10^{-6}	5×10^{-6} to 13×10^{-6}	13×10^{-6} to 1×10^{-3}	1×10^{-3} to 10	
180 to 302.5	30 J·m ⁻²							
302.5 to 315	For $t \leq T_1$, MPE = C_1 J·m ⁻² (Thermal hazard ^d) For $t > T_1$, MPE = C_2 J·m ⁻² (Photochemical hazard ^d)							
315 to 400								
400 to 450	1×10^{-3} J·m ⁻²		2×10^{-3} J·m ⁻²		$18 \text{ } t^{0,75}$ J·m ⁻²			
10^{-3} J·m ⁻²								
								10^{-3} J·m ⁻²
450 to 500	1×10^{-3} C_7 J·m ⁻²		2×10^{-2} C_7 J·m ⁻²		$90 \text{ } t^{0,75}$ C_7 J·m ⁻²			
500 to 700								
700 to 1 050	1×10^{-3} J·m ⁻²		2×10^{-3} C_4 J·m ⁻²		$18 \text{ } t^{0,75}$ C_4 J·m ⁻²			
1 050 to 1 400 ^e	1×10^{-3} C_7 J·m ⁻²		2×10^{-2} C_7 J·m ⁻²		$90 \text{ } t^{0,75}$ C_7 J·m ⁻²			
1 400 to 1 500	10^{12} W·m ⁻²		10^3 J·m ⁻²		$5\,600 \text{ } t^{0,25}$ J·m ⁻²			
1 500 to 1 800	10^{13} W·m ⁻²		10^4 J·m ⁻²		$5\,600 \text{ } t^{0,25}$ J·m ⁻²			
1 800 to 2 600	10^{12} W·m ⁻²		10^3 J·m ⁻²		$5\,600 \text{ } t^{0,25}$ J·m ⁻²			
2 600 to 10 ⁶	10^{11} W·m ⁻²		100 J·m ⁻²		$5\,600 \text{ } t^{0,25}$ J·m ⁻²			
a For correction factors and units, see Table 9; the exposure level that is compared with the MPE values is to be averaged over the appropriate aperture (Table 2).								
b The MPEs for exposure durations below 10 ⁻⁹ s and for wavelengths less than 400 nm or greater than 1 400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10 ⁻⁹ s. For all wavelengths the MPEs for exposure durations below 10 ⁻¹³ s are set to be equal to the equivalent irradiance values of the MPEs at 10 ⁻¹³ s.								
c In the wavelength range between 450 nm and 500 nm, dual limits apply and the exposure should not exceed either limit applicable.								
d For repetitively pulsed UV lasers, neither limit should be exceeded.								
e In the wavelength range between 1 200 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris), and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.								

Table 5 – Maximum permissible exposure (MPE) at the cornea for extended sources in the wavelength range from 400 nm to 1 400 nm (retinal hazard region) expressed as irradiance or radiant exposure

Wavelength λ nm	Exposure time, t s							
	10^{-13} to 10^{-11}	10^{-11} to $5,0 \times 10^{-6}$	$5,0 \times 10^{-6}$ to $1,3 \times 10^{-5}$	$1,3 \times 10^{-5}$ to 10	10 to 10^2			
400 to 700	$1 \times 10^{-3} C_6 \text{ J}\cdot\text{m}^{-2}$	$2 \times 10^{-3} C_6 \text{ J}\cdot\text{m}^{-2}$	$18 \rho^{0,75} C_6 \text{ J}\cdot\text{m}^{-2}$		400 nm to 600 nm – Retinal photochemical hazard ^a			
					$100 C_3 \text{ J}\cdot\text{m}^{-2}$ using $\gamma_{\text{ph}} = 11 \text{ mrad}$	$1 C_3 \text{ W}\cdot\text{m}^{-2}$ using $\gamma_{\text{ph}} = 1,1 \rho^{0,5} \text{ mrad}$	10^2 to 10^4	10^4 to 3×10^4
					AND ^b			
					400 nm to 700 nm – Retinal thermal hazard			
					For $t \leq T_2$, MPE = $18 \rho^{0,75} C_6 \text{ J}\cdot\text{m}^{-2}$ For $t > T_2$, MPE = $18 C_6 T_2^{-0,25} \text{ W}\cdot\text{m}^{-2}$			
700 to 1 050	$1 \times 10^{-3} C_6 \text{ J}\cdot\text{m}^{-2}$	$2 \times 10^{-3} C_4 C_6 \text{ J}\cdot\text{m}^{-2}$	$18 \rho^{0,75} C_4 C_6 \text{ J}\cdot\text{m}^{-2}$		For $t \leq T_2$, MPE = $18 \rho^{0,75} C_4 C_6 \text{ J}\cdot\text{m}^{-2}$ For $t > T_2$, MPE = $18 C_4 C_6 T_2^{-0,25} \text{ W}\cdot\text{m}^{-2}$			
1 050 to 1 400 ^c	$1 \times 10^{-3} C_6 C_7 \text{ J}\cdot\text{m}^{-2}$	$2 \times 10^{-2} C_6 C_7 \text{ J}\cdot\text{m}^{-2}$	$90 \rho^{0,75} C_6 C_7 \text{ J}\cdot\text{m}^{-2}$		For $t \leq T_2$, MPE = $90 \rho^{0,75} C_6 C_7 \text{ J}\cdot\text{m}^{-2}$ For $t > T_2$, MPE = $90 C_6 C_7 T_2^{-0,25} \text{ W}\cdot\text{m}^{-2}$			
NOTE Exposure limits for some ocular tissues may be different for ophthalmic instruments – see ISO 15004-2.								
^a The angle γ_{ph} is the limiting measurement angle of acceptance.								
^b In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure needs to 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 $100 C_3 \text{ J}\cdot\text{m}^{-2}$ should be applied for exposures greater than or equal to 1 s.								
^c In the wavelength range between 1 200 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris), and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.								