LASER SAFETY GUIDANCE NOTES

FOR

INDUSTRY, DISPLAY AND ENTERTAINMENT

2005 Edition

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Preface to 2005 Edition

In recent years, there has been much increase in use of lasers and rapid advancement in laser technologies and applications. The Laser Safety Guidance Notes for Industry, Display and Entertainment is published to promote awareness of laser safety and to provide general guidance on the proper use of lasers. It is not a statutory document. The owners, users, operators and manufacturers of laser equipment should be fully aware of the legal requirements under the prevalent legislations in Hong Kong.

Electrical and Mechanical Services Department

The Government of the Hong Kong Special Administrative Region

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PREAMBLE

Laser use is increasing in Hong Kong. They can be dangerous if safety precautions are not observed.

Laser safety has been a controversial topic ever since lasers began appearing in laboratories. Since then, much effort and many resources have been devoted to the subject. Various national and international laser safety standards and codes of practice are now available as a result of dedication, perseverance and collaborative effects of scientists and organisations around the world.

This publication is drawn up as a supplement to the operating manuals provided by the laser manufacturers. It provides guidelines on a number of fundamental areas relating to laser safety. It is strongly recommended that owners, users, operators and manufacturers should follow the guidelines in this publication closely in the interest of the safety of their staff, customers and others who may be at risk from the manufacture or use of laser equipment.

It should be noted that this publication stipulates only the basic and technical guidelines for the safe use of laser equipment. Owners, users, operators and manufacturers of laser equipment should also be fully aware of and conform to any relevant legal and technical requirements.

This publication consists of four separate parts plus a set of common technical annexes. The first part, Part 1, is a common introduction which provides basic information and guidance about lasers, their hazards and classification, and a recording system for laser equipment. It is relevant to all fields of laser application. The remaining three parts are specifically drawn up to provide guidelines for laser safety in three different spheres, details of which are as follows:

Part 2 : Guidance on the safe use of lasers in industry

Part 3 : Guidance for the manufacturers of laser products

Part 4 : Guidance on the safe use of lasers for display purposes

Most of them stem from the International Electrotechnical Commission Standard 60825-1:2001 (IEC 60825-1:2001) and are therefore equivalent in principle and nature except for the details pertinent to their specialization.

For other applications it is recommended that the relevant local and overseas safety materials be consulted. Reference materials for laser safety in education, medicine and dentistry and science and laboratories are as follows:

Laser Application	Corresponding Laser safety Reference Materials
(a) Education	(i) For Secondary Schools and Technical Institutes –- "Safety in Science Laboratories, Laser" Education Department, the Government of the Hong Kong Special Administrative Region, 2002.
	(ii) For Universities and Polytechnics – "Safety in Universities : Notes of Guidance, Part 2:1 Lasers" the Committee of Vice-Chancellors and Principals of the United Kingdom, Revised Edition 1992.

(b) Medicine and Dentistry	"Guidance on Safe Use of Lasers in Medical Practice" Hong Kong Medical Association 1994
(c) Science and Laboratories	"Safety in Universities: Notes of Guidance, Part 2:1 Lasers" The Committee of Vice-Chancellors and the Principals of the Universities of United Kingdom, Revised Edition 1992

Should owners, users, operators and manufacturers of lasers have any doubts or queries on laser safety, they are advised to consult the respective code of practice and reference materials; or the international standard series IEC 60825; or to contact the Government Laser Safety Officer* of the Electrical and Mechanical Services Department (EMSD) of the Government of the Hong Kong Special Administrative Region. Further copies of this publication are available from the EMSD.

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Part 1

Introduction to Lasers and their Hazards

1.1 INTRODUCTION

This part provides basic information and guidance about lasers, their classification and potential hazards and the recording system of laser equipment. They are relevant to all fields of laser application.

1.2 THE LASER

1.2.1 In general terms, a laser is a device that produces an intense, highly coherent and monochromatic beam of light, either visible or invisible. Normally this beam is almost parallel with low angular divergence.

1.2.2 The output from a laser is either in the form of a continuous beam or as a single pulse or a series of pulses. Lasers are often referred to as continuous wave (CW) lasers or pulsed lasers depending on their mode of operation. A laser operated with a continuous output for a period equal to or greater than 0.25 s is regarded as a CW laser and pulsed laser delivers its energy in the form of a single pulse or a train of pulses with pulse duration less than 0.25 s.

1.2.3 When describing a laser, it is normal to refer to the lasing medium, the power, and the mode of operation i.e. whether it is in continuous wave mode (CW) or pulsed mode. For example, the description of "a carbon dioxide 500W continuous wave laser" would properly describe this particular laser. Typical lasers used in various applications are:

(a) Gas Lasers

- (i) Argon (Ar)
- (ii) Carbon Dioxide (CO_2)
- (iii) Helium Neon (He-Ne)

(iv) Krypton (Kr)

(v) Excimer

(b) Liquid Lasers

(i) Dye

(c) Solid-state Lasers

(i) Neodymium-YAG (Nd-YAG)

(ii) Ruby

(d) Semiconductor (Diode) Lasers

(i) Gallium Arsenide (GaAs)

(ii) Indium Phosphorus (InP)

1.3 POTENTIAL HAZARDS

1.3.1 The hazards depend on a number of factors, including the wavelength of light it emits, the duration or intensity of the beam and the exposure duration. The eye is the main organ at risk, since if a visible or near infra-red beam enters the eye it may be focused on the retina to a minute spot whose diameter is between 10 μm and 20 μm. As a result of this focusing, the intensity is raised by a factor up to 200,000 times. Should a strong laser beam be focused at the fovea centralis, which is the area of most acute vision in the retina, blindness would be inflicted.

1.3.2 If the power intensity of the laser beam is high enough, skin damage can also result from exposure to the beam or its specular reflections. The pigmentation, ulceration and scarring of the skin and damage of underlying organs may occur from extremely high-power level irradiation. Certain wavelengths of laser light in the ultra-violet region may cause adverse effects similar to those produced by over-exposure to sunlight.

1.3.3 Many lasers have other hazards associated with their operation. These can include:

(a) high voltage stored in capacitors after the equipment is switched-off;

(b) high voltage during operation;

(c) toxic chemicals (for dye lasers);

(d) atmospheric contamination arising from:

  (i) toxic gases from some laser gas media;

  (ii) ozone produced by the electrical discharge;

  (iii) hazardous air contaminants from vaporised targets; and

  (iv) production of X-rays from high voltage discharge.

(e) associated fire hazards.

1.3.4 Full details of the potential biological hazards of laser are at Annex A.

1.4 MAXIMUM PERMISSIBLE EXPOSURE

1.4.1 The level of laser radiation to which, under normal circumstances, person may be exposed without suffering adverse effects is termed the maximum permissible exposure (MPE). The MPE level represents the maximum level to which the eyes or skin can be exposed without consequential injury, whether immediately or after a long time. MPE levels 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 – 1 400 nm, the size of the retinal image. Details of the maximum permissible exposure levels of the skin and the eye are at Annex B.

1.4.2 Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of a laser beam, the hazards arising from their use vary widely.

Therefore, MPE values would differ from one laser to the other depending on the types, modes and classes.

1.4.3 MPE values are set below known hazard levels, and are based on the best available information from experimental studies. The MPE values should be used as guides in the control of exposures and should not be regarded as precisely defined dividing lines between safe and dangerous levels.

1.5 CLASSIFICATION

1.5.1 According to the International Electrotechnical Commission Standard 60825-1:2001 (IEC 60825-1:2001), laser products are grouped into four general classes namely Class 1 (further subdivided into 1 and 1M), Class 2 (further subdivided into 2 and 2M) and Class 3 (further subdivided into 3R and 3B) for each of which accessible emission limits (AELs) are specified, and a Class 4 which covers lasers with outputs in excess of the specified AELs of Class 3B. The paragraphs below outline the international standard classification. Annex C contains details of the AELs for each class of laser. Annex D describes test measurements of laser radiation levels for classification purposes. Annex E gives a detailed description of laser product classes. The Annexes are based on IEC 60825-1:2001.

1.5.2 Class 1 lasers are those that do not permit human access to laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission durations. (see Table C.1 of Annex C)

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

1.5.4 Class 1M lasers are those that emit in the wavelength range from 302.5 nm to 4 000 nm while do 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 according to Annex D, however, evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 1 laser products. (see Table C.1 of Annex C)

1.5.5 Class 1M lasers are safe under reasonably foreseeable conditions of operation, but may be hazardous if the user employs optics within the beam. Two conditions apply:

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

(b) for a collimated beam with a diameter larger than the diameter specified in Table D.1 of Annex D for the measurements of irradiance and radiant exposure.

1.5.6 Class 2 lasers are those that do not permit human access to laser radiation in excess of the accessible emission limits of Class 2 for applicable wavelengths and emission durations. (see Table C.2 of Annex C)

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

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

1.5.8 Class 2M lasers are those that emit in the wavelength range from 400 nm to 700 nm while do 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 according to Annex D, however, evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 2 laser products. (see Table C.2 of Annex C)

1.5.9 Class 2M lasers emit visible radiation where eye protection is normally afforded by aversion responses including the blink reflex. However, viewing of the output may be more hazardous if the user employs optics within the beam. Two conditions apply:

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

(b) for a collimated beam with a diameter larger than the diameter specified in Table D.1 of Annex D for the measurements of irradiance and radiant exposure.

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

1.5.10 Class 3R and Class 3B lasers are those that permit human access to laser radiation in excess of the accessible emission limits of Class 1 and Class 2 as applicable, but which do 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.

1.5.11 Class 3R lasers emit in the wavelength range from 302.5 nm to 106 nm where direct intrabeam viewing is potentially hazardous but the risk is lower than for Class 3B lasers, and fewer manufacturing requirements and control measures for the user apply than for Class 3B lasers. The accessible emission limit is within five times the AEL of Class 2 in the wavelength range from 400 nm to 700 nm and within five times the AEL of Class 1 for other wavelengths. (see Table C.3 of Annex C)

1.5.12 Class 3B lasers may emit visible and/or invisible radiation at levels not exceeding the AELs specified in Table C.4 of Annex C. CW lasers may not exceed 0.5W.

1.5.13 Direct viewing into a Class 3B laser beam at a close distance is always hazardous. Viewing unfocused pulsed laser radiation by diffuse reflection is not hazardous and under certain conditions visible laser beams may safely be viewed via a diffuse reflector. These conditions are:

(a) a minimum viewing distance of 13 cm between screen and cornea ;

(b) a maximum viewing time of 10 s.

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

1.5.14 Class 4 lasers are high power devices with output powers exceeding those of Class 3B. Visible and near infra-red Class 4 lasers are capable of producing hazardous diffuse reflections. They may cause skin injuries and could also constitute a fire hazard. Their use requires extreme caution.

1.5.15 It is essential to ensure that all laser equipment is properly classified as different safety measures are needed for different classes of laser. Laser users should approach their supplier if they have doubts about the classification of their laser equipment. Laser users may also seek assistance on questions of classification from the Government Laser

Safety Officer of the Electrical and Mechanical Services Department.

1.5.16 The equipment owner should consult the supplier / manufacturer for re-evaluation and re-classification of their existing laser equipment in accordance with the latest standards.

1.6 EQUIPMENT MAINTENANCE AND SERVICING

In order to ensure that laser equipment can be safely operated throughout its useful life, it must be properly maintained and serviced in accordance with the recommendations of the manufacturer. Annex G contains an outline of the points that should be considered during the procurement stage. In general, the maintenance and servicing of laser equipment should be carried out by the manufacturer or his authorised agent. If there are any doubts about maintenance or servicing, the Government Laser Safety Officer may be consulted.

1.7 RECORD OF LASER EQUIPMENT

1.7.1 All users of laser equipment should maintain a record of their laser equipment. This should be done within three months of purchase. Annex F gives an outline of the type of information which should be kept.

1.7.2 The records should also include details of any subsequent changes and disposals.

Part 2

Guidance on the Safe Use of Lasers in Industry

2.1 INTRODUCTION

2.1.1 This guidance is for industrial laser users. It covers both the use of lasers indoors in factories or workshops and the use of lasers of various wavelengths for alignment and other surveys in the construction industry. The guidance:

(a) describes the hazards associated with some common types of lasers and used in industry;

(b) lists some relevant international and national standards for users' reference;

(c) gives guidelines concerning the procurement of industrial laser systems for users' consideration well before actual purchasing takes place;

(d) gives guidelines for the operation of enclosed and unenclosed laser systems, working indoors; and

(e) describes rules for handling laser beams working outdoors for construction alignment or other surveys.

2.1.2 Employers, employees and occupiers with laser installation in the workplaces should be aware of their general responsibilities for health and safety at work including laser safety.

2.2 HAZARDS ASSOCIATED WITH COMMON INDUSTRIAL LASERS

2.2.1 Laser beams are useful for industrial applications because of their coherence characteristics. The beam can be focused under control to a small zone of high power density. However, the same characteristics mean that laser beams are hazardous. A laser beam which is capable of melting and evaporating metals is clearly dangerous to biological tissues. Laser light which is visible is particularly hazardous to the eye. Visible light can be focused onto the retina of the eye with power density two hundred thousand times higher than the incident beam itself. The resulting damage is usually permanent. Invisible light can also be dangerous to the eye and the body. Depending on the wavelength of the light, the beam can be harmful to the retina, the cornea or the lens of the eye.

2.2.2 Two common types of lasers have been widely used in industry for materials working. They are Carbon Dioxide (CO_2) and Neodymium-YAG (Nd-YAG) lasers. CO_2 lasers are usually used for heavy materials cutting and welding. Nd-YAG lasers are commonly used in light industrial materials processing. Both are thermal processing lasers because their output beams are generated in the infra-red range. A third type of laser, the EXCIMER laser, has been increasingly used in industry in recent years. The outputs of excimer lasers are in ultra-violet range. These lasers are thus suitable for non-thermal processing for sensitive materials such as semi-conductors and chemicals. For construction alignment and anemometers, Helium-Neon lasers are commonly used. Argon ion lasers may also have industrial uses.

2.2.3 Some common safety precautions apply with these types of lasers. However, due to differences in the physical and engineering characteristics of the different types of lasers, special attention has to be paid to the specific hazards associated with their operation. These are set out below for each type of laser.

(a)* Carbon Dioxide lasers

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(i) There are two significant hazards associated with CO_2 lasers : high voltages and the laser beam itself. To operate the lasers, tens of kilovolts are needed. Users should refer to the pertinent standards for safe use of high voltage electrical equipment. As far as beam safety is concerned, it should be recognised that the beams from virtually all CO_2 lasers fall under Class 4 (see <u>Annex E</u> for an outline of laser classifications) and could cause skin or eye burns. The wavelength of CO2 laser is absorbed very strongly by tissue, so any damage is concentrated on the surface. Although the IEC 60825-1:2001 and ANSI Z136-1 standards for laser manufacturers require elaborate interlocks that make it difficult for operators to reach the beam and for unauthorised persons to operate the laser, the invisible infra-red beam does pose a potential hazard. Many materials-working CO_2 lasers are covered by plexiglass enclosures which are transparent to visible light but absorb the infrared laser beam.

(ii) The CO2 laser beam normally is invisible in air and when it is reflected off a surface, except at power densities high enough to significantly heat the surface or dust particles in air. Some CO2 lasers are packaged with Helium-Neon lasers with beams aligned collinearly, so that the red He-Ne laser beam traces the path of the invisible infrared beam.

(b) <u>Neodymium-YAG lasers</u>

(i) Neodymium lasers usually fall under Class 4. They produce light emission at a wavelength of 1060 nm which is invisible. In spite of its invisibility, light of this wavelength can still penetrate the eyeball and cause eye damage similar to that produced by visible light. The fact that most neodymium lasers produce intense pulses makes the situation more dangerous. There have been cases in which a single neodymium laser pulse, reflected unintentionally from an optical component, has caused an eye injury. Such reflections are more likely to occur when the beam is invisible. The most effective way to protect against such accidents is to wear safety goggles which transmit most visible light whilst blocking laser radiation of 1060 nm wavelength.

(ii) Short and intense pulses of harmonics of neodymium lasers are also hazardous to the eye. The second harmonic at 532 nm is in the visible green portion of the spectrum and is capable of penetrating the eye. The presence of the green light radiation poses problems for the design of safety goggles for eye protection. Hazards from higher harmonics are different from those at longer wavelengths and from each other. The shorter of the two ultra-violet wavelengths can cause a sunburn-like effect on the skin as well as endangering the eye. There are safety goggles which can provide eye protection against radiation at these two wavelengths.

(iii) Multi-wavelength laser output can present serious hazards to the eye due to the difficulty of designing safety goggles to block light at two or more separated wavelengths. As a rule, users should select suitable goggles which are able to filter all hazardous wavelengths of the output beam but which do not block the light necessary for safe operation of the equipment. If non-linear optical components are to be used, care should be taken as various harmonics will possibly be emitted.

(iv) Flashlamps used to pump neodymium lasers pose two distinct hazards: high voltages in the power supply and explosion of overloaded lamps. Users should refer to the relevant international standards for safe use of high voltage electrical equipment. Flashlamps can explode if pulsed at excessive power levels.

(c) Excimer lasers

(i) Four potential hazards are associated with the use of excimer lasers, namely : high voltages, X-rays used for pre-ionization in certain models, ultra-violet light and the laser gases themselves.

(ii) Tens of kilovolts are required to enable discharging within excimer lasers for optical pumping. These high voltages are stored and switched within the laser and the power supply. Care should be taken that all stored voltages have been dissipated before checking inside the laser. The relevant international standards should be referred to for guidance on handling high voltage electrical equipment.

(iii) If X-rays are used to pre-ionize the laser gas, they could pose a radiological hazard. Such products should come with proper shielding and warning labels to allow safe operation. The use of X-ray should be under the control of Radiation Ordinance.

(iv) Short, powerful ultra-violet pulses are hazardous to the eye, and ultra-violet exposure can also be harmful to the skin. Pulses with wavelengths longer than about 315nm can cause retinal damage. Annex B provides guidance on calculating the exposure limits for emission of various wavelengths. Annex C gives the relevant limits concerning laser safety. Ultra-violet radiation of shorter wavelengths does not reach the retina but is absorbed in the cornea, where they can cause a painful but temporary sunburn-like effect called "snow blindness" or "welder's flash". Ultra-violet light can also present danger to the lens of the eye. Skin exposure can lead to the same effects as over-exposure to the sun's ultra-violet rays. Shielding of ultra-violet emissions from the laser working area can be achieved by using suitable protective screens. This measure is needed to avoid the above dangers.

(v) The halogens in the excimer lasers are not innocuous. There are standards limiting exposure to the gases involved. For fluorine, the limit is 0.1 ppm in air, for chlorine, 1 ppm; and for NF_3, 10 ppm. Pure fluorine is so corrosive that it presents potential fire and explosion hazards. To avoid dangers, fluorine in excimer lasers is normally diluted to 5% concentration by adding helium, and the diluted gas supplied in cylinders. Users should refer to the pertinent international standards for guidance on handling toxic gases.

(d) Helium Neon lasers

(i) Laser power of several milliwatts or less is not fatally dangerous and may not even be felt as a warm spot on the skin. However a Helium Neon (He-Ne) laser beam has an intensity comparable to that of sunlight. They are both made of parallel rays. The eye can focus both onto very small spots on the retina. If the exposure time is long, the intensity at the retina can be high enough to cause permanent damage. However, an accidental glance into a low-power He-Ne laser need not be a cause for concern as it is no more likely to cause instantaneous blindness than an accidental glance at the sun. Nevertheless, particular care should be taken with high-power He-Ne lasers, especially those of Class 3B and Class 4.

(ii) The basic rule for the safe use of He-Ne lasers are to avoid staring into the laser beam and to avoid coming into contact with the high voltages that power the discharge.

(e) Argon Ion lasers

(i) Argon lasers fall under Class 3B or Class 4. Users should take care to avoid direct exposure to the beam, particularly eye exposure. Unattenuated argon's blue-green lines can be dangerous. The unattenuated, narrow-divergence beam from an argon laser can penetrate the eyeball and permanently affect the retina.

(ii) The ultra-violet lines of the argon laser beam are strongly absorbed by the lens of the eye, and only a small fraction of such light reaches the retina. There are few continuous-wave lasers emitting at these wavelengths, and eye hazards are not well quantified, so the use of ultraviolet absorbing goggles would be a prudent precaution.

(iii) Like other discharge-driven lasers, ion lasers need high voltages, but only to initiate the discharge. After the discharge is established, voltage drops to the 90-V to 400-V level, with currents of 10 A or more flowing through the tube. The hazards presented by such levels of current capacity are different from those at higher voltages, resembling the dangers of an open wall socket.

2.3 STANDARDS

2.3.1 Users of industrial laser systems should note the existence of the following national, state and international standards.

(a) International Electrotechnical Commission IEC 60825-1:2001 Safety of laser products – Part 1: equipment classification, requirements and user's guide

(b) British Standard European Standard BS EN 60825-1:1994 Safety of laser product: equipment classification, requirements and user's guide

(c) American National Standard ANSI Z136.1-2000 American National Standard for the safe use of lasers

(d) US Department of Health and Human Services "Performance Standard for Laser Products." Code of Federal Regulations, Title 21, Subchapter J, part 1040.10, 1985

Standards (a) to (c) are voluntary while (d) is compulsory.

2.4 PROCUREMENT OF INDUSTRIAL LASER SYSTEMS

2.4.1 Planning in the early stages of procurement of industrial laser systems is essential. Users of industrial laser systems need to address issues of budgetary and space requirements with respect to personnel to manage safety rules, expenditure on laser safety equipment and the designation of a Laser Controlled Area.

2.4.2 Potential users of industrial laser systems should know in advance the class of the laser installations to be purchased. If they have difficulties in assessing the laser classifications of their intended installations, they should contact the dealers, the suppliers and/or the manufacturers for the information. The Government Laser Safety Officer of the Electrical and Mechanical Services Department of the Government of the Hong Kong Special Administrative Region can be consulted if needed.

2.4.3 The information that manufacturers of laser systems should supply to purchasers, serving dealers and distributors of laser systems is listed in Annex G.

2.4.4 Users are required to plan, in advance, control measures appropriate to the classes of the lasers and laser systems they intended to install. Where practicable, the measures for Class 3R for non-visible emission, Class 3B and Class 4 lasers should include the following:

(a) appointment of a Designed Laser Safety Officer[*];

(b) the drawing up of specific internal safety codes of practice for each specific piece of laser equipment;

(c) designation of a Laser Controlled Area;

[*] For the purposes of this part, the "Designated Laser Safety Officer" is a person appointed or recognised by the laser user. The Laser Safety Officer of the Electrical and Mechanical Services Department is termed the "Government Laser Safety Officer".

(d) incorporation of an Engineering Controls Scheme;

(e) organisation of an Administrative and Procedural Control Structure;

(f) the provision of all necessary tools and suitable personal protective equipment;

(g) the posting of appropriate warning signs at all entrances to the Laser Controlled Area; and

(h) the provision of training, education and medical surveillance.

2.4.5 Not all the above control measures may be required but the Designated Laser Safety Officer should have unequivocal reasons to rule out any of them. Details of the above control measures are given in IEC 60825-1 and ANSI Z136-1. They are tabulated in Annex H.

2.4.6 Laser systems of Class 3R for visible emission and below may not require the above control measures but appropriate procedures and warning signs should be prepared to ensure no direct viewing of beams either emerged or specularly reflected from the laser sources. It should be noted that such lasers may become Class 3B or Class 4 if the system is modified or under maintenance. Should this be the case, paragraph 2.4.4 above is applicable.

2.4.7 Purchasers, serving dealers and distributors have to make certain that the laser systems they are concerned with are made and classified according to the international standards listed in paragraph 2.3.1 above. Any other systems not complying with any one of those standards should be considered as unclassified products. Unclassified products should be treated with particular caution so far as laser safety is concerned. Unless they are reclassified and relabelled in accordance with the standards, the laser systems should be considered as Class 4 lasers and the control measures set out in paragraph 2.4.4 above should be applied. Annexes D and E give guidance on classifying laser products.

2.4.8 Reclassification tests should be carried out by qualified persons under the supervision of the Designated Laser Safety Officer.

2.4.9 Firms which intend to purchase and use laser systems should make certain that they are able to implement the required safety controls appropriate to the class of the equipment concerned before they install it. It should be noted that if laser installation, modification and repair work is done after reclassification, safety precautions should be taken according to the new classification.

2.4.10 As indicated in paragraph 1.7.1 of Part 1, all users of laser equipment should maintain a record of that equipment. Annex F gives on outline of the type of information which should be kept.

2.5 SAFETY WITH INDUSTRIAL LASER SYSTEMS

For laser safety, it is very important to realize that safety control measure must be appropriate to the given class of the laser in question. Users need not adopt too many measures but should not adopt fewer than are required. Laser safety controls are a lot easier for enclosed laser systems than for unenclosed ones. Users should seek products of the enclosed kind: manufacturers nowadays are keen to produce enclosed systems where practicable. However, users should be fully aware of the essential meaning of the term “enclosed system” and the conditions under which enclosed systems become unenclosed.

2.5.1 Use of totally enclosed systems in factories and industrial undertakings

2.5.1.1 All such laser systems must be labelled in accordance with the details given in Annex I.

2.5.1.2 A totally enclosed system is one which a laser (lasers) is (are) installed and totally fenced off from outside which it is not possible for personnel to be exposed to radiation in excess of the Accessible Emission Limits for a Class 1 laser.

2.5.1.3 For such a system, most of the control measures outlined in paragraph 2.4.4 above need not normally be applied. If, however, it is necessary for personnel to gain access to the enclosure, for maintenance, setting up and allied operations, the laser(s) must be reclassified for the duration of those operations and the appropriate controls implemented.

2.5.1.4 In order to qualify for inclusion under this heading, the following additional points must be observed:

(a) The enclosure must be clearly labelled

(b) Interlocks must be provided such that it is not possible, during normal operations, to remove any part of the enclosures and by so doing to expose oneself or others to radiation in excess of accessible emission limits for a Class 1 laser. This should include covering radiation from working pieces of materials which may be reflective to laser beams.

(c) The laser(s) and its enclosure must be designed on a "fail-safe" basis so that adjustments, alterations and failures of any part of the system will not invalidate the requirements relating to the levels of the exposure outside the enclosure, or result in the system becoming unsafe in other respects.

(d) The laser(s) within the enclosure must be clearly identified and labelled in accordance with the requirements for the appropriate class given in Annex I.

(e) An electrical isolation switch for the whole of the system must be provided. This must be clearly labelled and sited in a conspicuous and convenient position.

2.5.1.5 When the safety interlock systems have to be modified, the manufacturers concerned must be consulted.

2.5.2 Use of unenclosed laser systems

The following points must be observed for the appropriate class of lasers:

2.5.2.1 Class 1 lasers

(a) All such lasers must be labelled in accordance with the details given in Annex I.

(b) If the lasers are so small in size or so numerous in volume that labelling is impracticable, e.g. semiconductor diode lasers, they should be labelled at an appropriate position as close as possible to the lasers when in use.

2.5.2.2 Class 1M, Class 2, Class 2M and Class 3R lasers

(a) All such lasers must be labelled in accordance with the details given in Annex I.

(b) Precautions must be adopted to prevent continuous viewing of the direct beam and to control the use of optical viewing aids, such as microscope, binoculars etc., so that the maximum permissible exposure levels are not exceeded.

(c) The use of optical viewing aids (for example, binoculars) with Class 1M, Class 2M and Class 3R laser products may increase the ocular hazard and should be avoided as far as possible. Additional precautions such as the use of video monitor should be considered.

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

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

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

(g) Precautions should be taken to ensure that persons do not look directly into the beam (prolonged intrabeam viewing can be hazardous). Direct viewing of the beam through optical instruments (theodolite, etc.) may also be hazardous, particularly for Class 1M and Class 2M lasers that failed condition 1 of Table D.1 of Annex D and should not be permitted unless specifically approved by a Designated Laser Safety Officer.

(h) The laser beam should be terminated at the end of its useful beam path and should in all cases be terminated if the hazardous beam path (to normal ocular hazard distance) extends beyond the Controlled Area.

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

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

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

(l) Laser beams must never be deliberately aimed at people even when they are under the integrated control of a robotic system.

2.5.2.3 Class 3B and Class 4 lasers

(a) A register must be kept of all such lasers, which must be labelled in accordance with the details given in Annex I.

(b) Class 3B lasers present a hazard to the eye if the direct beam or its specular reflections are viewed without the protection afforded by features of the design or by suitable goggles.

(c) Class 4 lasers present an even greater hazard to the eyes, as well as to the skin; exposure to diffuse reflections can also be dangerous to the eyes and skin; and in addition, can constitute a serious fire hazard. It must be recognized that this class embraces all lasers with power outputs in excess of 0.5 W. Now that lasers with outputs of terawatts are available. This is a very wide range indeed, and it is clear that, for safety considerations, not all lasers in this class can be treated alike.

(d) The actual precautions needed for each Class 3B or Class 4 laser installation should be carefully planned in advance by the management of the firm and the Designated Laser Safety Officer. Nevertheless, lasers of either of these classes must only be used in Laser Controlled Areas : that is, factory shop floors or clearly defined places in the premises which are set aside for laser use and where the hazards can be effectively controlled. Users may also wish to consider the inclusion of some Class 2 and totally enclosed systems in such areas.

(e) Laser Controlled Areas must be clearly identified. The warning sign shown in Figure I.1 of Annex I must be used for this purpose and must be incorporated in a suitable notice which must be displayed at all the entrances to each Laser Controlled Area. Consideration should also be given to the provision of a suitable visual signal sited at the entrances to the area and interlocked with the laser, so that it functions whenever the laser is being operated.

(f) Entry to a Laser Controlled Area should normally be limited to authorised personnel only. No other personnel should enter the area when the laser is actually in use. The notice details in paragraph 2.5.2.3 (e) above should make this clear. Visitors to such areas must be accompanied by qualified persons and authorised by the Designated Laser Safety Officer with the endorsement of superior.

(g) In certain special cases, for instance when high-powered pulsed lasers are used, an interlock on the door leading into the area should be provided to prevent entry when the laser is in use. A visual signal at the entrance to the area to indicate the laser's state of readiness to emit laser radiation should be provided. If this procedure is found to be necessary, care must be taken to ensure that the device does not hinder the ready exit of personnel working in the area, or access to emergency services. Arrangements must also ensure that personnel will not work alone behind locked doors. Alternatively some means of breaking the interlock must be devised for use in case of emergency.

(h) Where possible, only one laser should be used in any one Laser Controlled Area at any one time. If this is not possible, consideration should be given to the use of suitable opaque (opaque to visible and invisible laser radiation) screens for separation.

(i) The Laser Controlled Area must be constructed and equipped in order to minimise the risk to authorised persons working in the area, both from the laser itself and from associated electrical, mechanical, chemical and other hazards. It must also provide protection to people outside the area and temporary visitors.

(j) Each Laser Controlled Area should be purposely designed for the particular laser application. Moreover, some of the more important aspects which must be considered in designing the Laser Controlled Area are:

  (i) If it is not reasonably practicable to "box-in" the laser beam then consideration must be given to the total exclusion of laser beam leakage from the area.

Careful siting of the laser within the area will help to eliminate the possibility of leakage through doors and windows, but “blacking-out” may still be necessary.

(ii) The provision of a suitable beam stop or target in which to terminate the laser beam. This must be capable of absorbing the energy concerned and have the fire resistant characteristics necessary for the particular laser. In general, it should be matt black, although it is recognised that circumstances may dictate other finishes.

(iii) The provision, wherever possible, of a high standard of general illumination within the area, so that the pupil of the eye remains as small as possible.

(iv) The painting, whenever possible, of walls, ceilings and fittings within the Laser Controlled Area with a light coloured matt paint to enhance the general illumination and reduce specular reflections.

(v) The removal of all unnecessary equipment from the Laser Controlled Area.

(vi) The minimisation and, if possible, the elimination of reflecting surfaces. Glass fronted cupboards and gloss painted items of electrical and other equipment are obvious examples.

(vii) The provision, where necessary, of adequate ventilation to prevent build-up of air contaminants, either from the contents of the lasers themselves, or from materials irradiated by the lasers. The use of materials such as liquid oxygen presents a further hazard which must not be ignored. Reference should be made to the “Code of Practice on Control of Air Impurities (Chemical Substances) in the Workplace” prepared by the Occupational Safety and Health Branch, Labour Department.

(viii) The provision, where necessary, of adequate facilities for the dispensing and handling of toxic chemicals, such as, for example, those used in dye lasers some of which may well be carcinogenic. Thought must also be given to the manner in which toxic wastes will be dealt with and removed from the premises.

(ix) Beam paths should be kept well below eye-level and enclosed (e.g. within a tube or boxed-in) whenever practicable. Boxing-in and screens should be opaque to the laser wavelengths involved and should be designed to prevent hazardous specular and diffuse reflections. Where necessary they should be painted with matt black paint and be constructed of fire-resistant material. When complete the assembly should eliminate as far as reasonably practicable the possibility of any part of the body being accidentally placed in a hazardous area. The question of whether these should be interlocked with the laser control system should also be considered.

(x) The mounting and fixing of the laser and associated equipment in order to prevent accidental movement and hence unexpected direct or reflected beams. If the laser is mounted on a moving arm, interlock systems have to be devised to restrict the beams directing only to the working pieces without reflections.

(xi) The siting of approved electrical supplies with identified switch and control gear designed:

(1) to prevent accidental firing of the lasers;

(2) to provide an indication of the state of readiness of equipment such as associated capacitor banks;

(3) to enable personnel to stand in a safe place;

(4) to incorporate all relevant electrical safety features;

(5) to enable the laser to be shut down by a person standing next to the laser;

(6) to enable the equipment to be isolated and made safe from outside the Laser Controlled Area in the event of fire or other emergency; and

(7) to provide sufficient and adequate power supplies for all the ancillary equipment and apparatus, and to restrict the use of trailing leads (which must in any case be adequately secured) to an absolute minimum.

(xii) The provision of adequate and appropriate fire-fighting equipment.

(k) Even with all the design features listed above incorporated into the laser system and the Designated Laser Safety Area and with carefully thought out administrative controls, there will probably still be times when access is required to open beams during alignment and maintenance procedures. At times like this the appropriate eye protection in accordance with paragraph 2.5.2.3 (l) must be used.

(l) Consideration should be given to the use of appropriately coated optical components. Select components which will not shatter or craze under the influence of the laser beam; to the removal of unwanted apparatus, furniture and equipment from the laser area and the elimination of reflective surfaces from items which have to remain; to the removal of personal jewellery, wrist-watches, etc, and to the covering of shiny buttons, belt buckles, etc, with a suitable laboratory coat or coverall.

2.6 SAFETY WITH LASER SYSTEMS FOR OUTDOORS ALIGNMENT AND SURVEYS

2.6.1 The use of lasers of any class on construction sites or factory premises out of doors necessitates special precautions to deal with the problems of public safety and public relations which such work poses, particularly when the public have access to such areas. In particular the laser beam must normally be terminated completely within the experimental area, which must be positively defined and clearly indicated. In those cases where the beam of a laser has to be directed upwards, the need for consultation with the Civil Aviation Department should be considered. The Designated Laser Safety Officer should evaluate the effect on aviation safety. Under normal circumstances, laser beam should not be directed skywards.

2.6.2 If it is intended to use a laser out of doors, a Designated Laser Safety Officer should be appointed to give advice on what detailed action is required. To ensure the safety of the public, lasers should in no circumstances be used outdoors until formal written permission has been granted by the Designated Laser Safety Officer.

2.6.3 The use of lasers outdoors on premises not owned by the firms carrying out the works will inevitably raise questions relating to responsibility, liability and insurance. Legal advice must be sought before embarking upon laser use outdoors. Suitable assurances should be obtained for any accidental injuries and damage, etc. which may be incurred.

2.6.4 The operator should act on any advice of the Designated Laser Safety Officer. The former should follow carefully any regulations, codes of practice or other instructions regarding the use of lasers which might apply specifically to the premises concerned or, in the absence of any such documents, work in accordance with those sections of this document which may be pertinent. If there is any doubt, he should consult the Designated Laser Safety Officer immediately.

2.6.5 Lasers of Class 1 or Class 2 should be used for surveying, alignment, and levelling applications whenever practicable. There may be situations, however, where high ambient light levels require the use of lasers of higher output power. If Class 1M, Class 2M and Class 3R lasers are used, the requirements of paragraph 2.5.2.2 should be followed. In those exceptional cases where Class 3B lasers are necessary, the requirements of paragraph 2.6.6 should be followed. In addition, human access should not be permitted to laser radiation in the wavelength range from 400 nm to 700 nm with a radiant power that exceeds $5 \times 10{-}3$ W for any emission duration exceeding $3.8 \times 10{-}4$ s nor should human access be permitted to laser radiation in excess of the AEL for Class 1 for any other combination of emission duration and wavelength range.

2.6.6 Class 3B and Class 4 lasers in outdoor and similar environments should only be operated by personnel adequately trained in their use and approved by the Designated Laser Safety Officer. To minimize possible hazards, the following precautions should be employed in addition to those given in paragraph 2.5.2.2.

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

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

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

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

(d) Direct intrabeam viewing of Class 3B lasers is always hazardous. Viewing unfocused pulsed laser radiation by diffuse reflection is not hazardous and, under certain conditions, visible laser beams may safely be viewed via a diffuse reflector. These conditions are:

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

– a maximum viewing time of 10 s.

If the conditions are not satisfied, careful evaluation of the potential diffuse reflection hazard is necessary.

2.7 MEDICAL EXAMINATIONS

2.7.1 Whilst the validity of the medical surveillance of laser workers is as yet unresolved by the medical profession, the Controlling Authority (e.g. the management of a firm) is advised to arrange for medical supervision by an appointed Medical Adviser (who may be a G.P.) for all personnel working with Class 3B and Class 4 lasers. The Medical Adviser should make arrangements for the examination of the eyes by a Consultant Ophthalmologist and for such other examinations as he may consider necessary. He should also be available for consultation in the event of an accident.

2.7.2 The following recommendations should be taken into consideration in order to comply with the international standards:

(a) The value of routine ophthalmic examination of workers using laser products is unproven. If ophthalmic examinations are undertaken, they should be carried out by a qualified specialist and should be confined to workers using Class 3B and Class 4 laser products.

(b) A medical examination by a qualified specialist should be carried out within 24 hours after the alleged occurrence of a suprathreshold ocular exposure. Such an examination should be supplemented by a full biophysical investigation of the circumstances under which the accident occurred. It is recommended that copies of both these studies should be referred to a central agency* and the necessary steps should be initiated to prevent recurrence of similar accidents.

(c) Pre-, interim- and post-employment ophthalmic examinations of workers using Class 3B and Class 4 laser products may have value for medical and/or legal reasons but are not necessarily part of a safety programme.

2.7.3 When the Medical Adviser so recommends, in writing with sufficient evidence, the Controlling Authority must ensure that a person is suspended from work with lasers and is not allowed to resume such work without approval of the Medical Adviser.

2.8 DESIGNATED LASER SAFETY OFFICER

2.8.1 For laser installations with Class 3R for non-visible emission, Class 3B or Class 4 laser(s) or where lasers are to be used out of doors, a Designated Laser Safety Officer should be appointed who should have sufficient knowledge and training to be able to advise the firm on necessary precautions.

2.8.2 Preferably, the Designated Laser Safety Officer should have the responsibility and authority to conduct safety and health risk assessments, and advise the responsible persons on appropriate control measures. He/she should also have the responsibility and authority to monitor and enforce the control of the laser hazards and effect the knowledgeable evaluation and control of laser hazards. For example, he may need to

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* Government Laser Safety Officer
Electrical and Mechanical Services Department
3 Kai Shing Street,
Kowloon,
Hong Kong
(Tel.: 1823)

undertake calculations to set nominal ocular hazard distances and possibly reclassify the laser after modification. He may also need to undertake spontaneous checks to ensure that safety measures are being complied with.

2.8.3 In the event of a laser accident, the Designated Laser Safety Officer should be responsible for reporting the accident to the Government Laser Safety Officer and where appropriate, the Commissioner for Labour. He should conduct a detailed investigation for any accident and make the results known to all parties concerned. He should take remedial measures to prevent similar accidents.

2.8.4 Depending on the number of Class 3B and Class 4 lasers in the industrial establishment, the Designated Laser Safety Officer may be a member of staff carrying out the duty on a full- or part-time basis or a qualified individual from an external consultancy firm.

Part 3

Guidance for the Manufacturer of Laser Products

3.1 INTRODUCTION

3.1.1 This guide should be used as a compliance guide by all Hong Kong manufacturers of laser products, whether the product is to be used in Hong Kong or abroad.

3.1.2 If the product is intended for use abroad, the manufacturer should also refer to the safety requirements of the countries concerned.

3.1.3 Compliance with this guide does not assure compliance with laser safety requirements in countries other than Hong Kong. For example, laser products for export to the United States have to comply with the United States Code of Federal Regulation Title 21, Chapter I, Sub-chapter J, Part 1000 to 1010, 1040.10 and 1040.11. There are differences between the requirements of the United States Federal and the recommendations of this guide.

3.2 BASIC DEFINITIONS SPECIFIC TO THIS PART

The following definitions apply for the purposes of this part:

(a) Manufacturer This covers any individual or organization making, assembling, importing or re-exporting laser products.

(b) Laser Product This covers any device that constitutes, incorporates, or is intended to incorporate a laser or a laser system.

(c) Operation or Maintenance Those tasks covered by the user, as detailed in the user instruction manuals and literature.

(d) Service Tasks which are performed by a qualified service engineer.

3.3 SUMMARY OF REQUIREMENTS AND RECOMMENDATIONS

Manufacturers should:

(a) design and manufacture their products to be in compliance with this guide;

(b) test their products to assure compliance;

(c) certify compliance of their products;

(d) maintain records of (a), (b) and (c) above, plus distribution record and a file of correspondence concerning all safety-related topics;

(e) report any physical accidents or injuries related to the manufacture or use of their products, to the Electrical and Mechanical Services Department of the Government of the Hong Kong Special Administrative Region; and

(f) make all reasonable effort to recall , replace or repair any defective or non-compliance products.

3.4 DESIGN AND MANUFACTURE OF THE LASER PRODUCT TO COMPLY WITH THE STANDARD

(a) In designing laser products, manufacturers must first determine the level of laser radiation to which human access is possible during operation function. Laser radiation to which human access is not necessary must be eliminated or contained within a protective housing. Human access is defined as:

(i) the capability for a part of the human body to meet hazardous laser radiation either as emitted from an aperture, or capability for a straight 12 mm diameter probe up to 80 mm long to intercept laser radiation of Class 2, Class 2M or Class 3R, or

(ii) for levels of laser radiation within a housing that exceed the limits in (i) 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.

(b) Manufacturers must therefore determine the class of their products (see Tables C.1 to C.4 of Annex C, and Annex E) according to the highest level of laser radiation accessible during the operation. The class of the product determines warning on the product and warnings in its literature. The wording of any required warning is based on the injury-causing potential of accessible laser radiation. Annex J summarizes the requirement of this guide.

(c) For requirements related to access to laser radiation which is not possible during operation, but which is possible during maintenance or servicing, refer to the sections on labelling and safety interlocks below.

3.4.1 Measurements

(a) Measurements to determine classification must be made with the measuring instrument positioned for maximum detection and with all controls on the laser product adjusted to achieve maximum emission. If calculations are used instead of measurements, all values must be justified and must represent a worst-case analysis.

(b) All measurements, procedures and test data forms must be kept on file by the manufacturer for the future reference for a minimum of five years after last release of that product. Refer to Annex D for the details of testing instruments and procedures.

3.4.1.1 Multiple or diverging beams, diffuse sources

All radiation within a solid angle of acceptance of 10^{-3} steradians must be included in the measurement. If necessary, therefore, collimating optics will have to be used to achieve the measurement. The collimating optics used must have a focal length longer than 20 cm (total optical power being less than 5 diopters).

3.4.1.2 Scanned Beams

If the laser radiation is scanned, measurements of radiant energy and power are made with a 7mm diameter circular aperture having a solid angle of acceptance of 10^{-3} steradians with collimating optics of 5 diopters or less. If the angular rate of scanning is less than 5 radians/second, the direction of the solid angle of acceptance must also track the scan.

3.4.1.3 Classification

(a) Products are classified according to the maximum level of laser radiation within human access during operation only. Levels accessible only during maintenance or service do not affect the classification. Hence, it is possible for Class 1 products to contain Class 4 lasers.

(b) If the limit of a class is exceeded at any emission duration, the product cannot be in the class, all possible emission durations must be considered, ranging from single nanosecond pulses (10^{-9}s) to the very long term average (greater than 10 seconds).

3.4.2 Design criteria

(a) A protective housing is required for all laser products. The protective housing must be designed to minimize all human and instrument access to the beam or reflected beam, as well as to high tension power circuits. Manufacturers must be able to justify that the protective housing encompasses all aspects of laser radiation which are not necessary for the function of the product.

(b) Access panels of protective housings intended to be removed or displaced during maintenance or operation thereby giving the human access to laser radiation from the embedded laser in excess of the AEL of Class 3R or in excess of the AEL of the class assigned, should be provided with a safety interlock. The safety interlock should be of a design which prevents the removal of the panel until accessible emission values are below the AEL for the class assigned and inadvertent resulting of the interlock should not in itself restore emission values above the AEL of the class assigned.

(c) In cases of service or maintenance operations, a safety interlock override device may be necessary. This too must be fail-safe. It should be key operated and should provide visible and/or audible warning if the override is engaged. (Visible warnings should be of a different wavelength to that of the beam).

(d) A remote interlock connector is recommended for all Class 3B and Class 4 laser systems. This would usually take the form of an “emergency stop” button in series with the safety interlock. This too must be fail-safe.

(e) A key control is recommended for all Class 3B and Class 4 laser systems, in order for the user to prevent unauthorized operation. The key must not be removable in the “on” position.

(f) An emission warning device is recommended on Class 3R laser systems in the wavelength range outside the visible spectrum (i.e. outside the range of 400 nm to 700 nm), and on Class 3B and Class 4 laser systems. The indicator can be visible or audible. The indicator must precede emission by a length of time sufficient to allow users and others in the area to recognize so they can avoid exposure. Depending on the action required and the level of the laser radiation involved, the time needed can vary considerably; typical values are in the range of 2 to 20 seconds. Emission indicators must be duplicated on lasers (heads) and operation controls if they are capable of being separated by greater than 2 meters.

(g) A beam attenuator is recommended on Class 3B and Class 4 laser systems. The beam attenuator is a mechanical or electro-mechanical device such as a shutter or attenuator that blocks emission. The beam attenuator blocks bodily access to laser radiation above Class 1M or Class 2M as applicable limits without the need to turn off the laser. The beam attenuator must be available for use at all times during operation. Power switches and key controls do not satisfy the beam attenuator requirement.

(h) Operation controls on Class 3R, Class 3B or Class 4 laser products must be located such that it is not necessary for the user to be exposed to radiation while manipulating them.

(i) Viewing optics, viewports, or display screens may not provide human access to laser or collateral radiation in excess of the limit of Class 1M during operation or maintenance. If the viewing optics employ a shutter or variable attenuator must be fail-safe; that is it must be designed such that, upon failure, it is impossible to open the shutter or vary the attenuation. Viewing optics include such devices as viewports, windows, microscopes on welding and drilling devices, and operating microscopes on surgical lasers. Attenuation may be total, or it may be partial as with a filter. Acceptable designs may prevent laser operation until the attenuator has moved into position. Service instructions must include instructions on procedures to avoid hazardous exposure through viewing optics.

(j) A scanning safeguard must prevent emission in excess of the limits of the class of the products. For Class 3B or Class 4 laser products that operate in both scanned and unscanned modes, the scanning safeguard must also prevent emission in excess of the limits of the class of the scanned laser radiation (and whose failure would result in emissions exceeding Class 3R). Scanning laser is laser radiation that is moved in translation or by changing direction. A scan failure safeguard must have a reaction time short enough to operate before levels of a higher class are emitted;

it is possible to achieve this performance by means of a high inertia scanner in conjunction with an electro-mechanical shutter.

(k) A manual reset is recommended on Class 3B or Class 4 laser systems. It must prevent automatic restart after an interruption due to remote interlock activation or from an interruption for more than five seconds due to unexpected loss of main electrical power.

3.4.3 Labelling criteria

3.4.3.1 Each laser product shall carry label(s) in accordance with the requirements specified in Annex I. The labels shall be permanently fixed, legible and clearly visible during operation, maintenance or service, according to their purpose. They shall be so positioned that they can be read without the necessity for human exposure to laser radiation in excess of the AEL for Class 1. Text borders and symbols shall be black on a yellow background. If the size or design of the product makes labelling impractical, the label should be included with the user information or on the package.

3.4.3.2 All wording on the labels should be in English and Chinese. Annex I gives the details.

3.4.4 Information requirements

3.4.4.1 Informational requirements apply to user information for operation and maintenance, to purchasing information such as brochures and specification sheets, and to servicing information.

3.4.4.2 User information must contain:

(a) instructions for operation and maintenance, with appropriate warnings to avoid exposure;

(b) radiation specification;

(c) reproductions and locations of labels that are required by the standard and that are accessible during operation and maintenance;

(d) a listing of all controls and adjustments ; and

(e) a caution statement concerning possible hazardous exposure if instructions are not followed.

3.4.4.3 Brochures and specification sheets must include a reproduction (color optional) of a complete warning logotype or appropriate warning statement as required on the product.

3.4.4.4 Servicing information must contain:

(a) procedures for service with appropriate warnings to avoid exposure;

(b) a schedule of maintenance to maintain the product in compliance;

(c) a listing of controls that could increase the level of accessible radiation;

(d) identification of removable portions of protective housings;

(e) procedures to avoid exposure; and

(f) reproductions of required labels (color optional) and warnings.

3.4.4.5 At the discretion of the manufacturer, user and service information may or may not appear in the same manual. Service procedures, however, must be clearly identified as such. In many cases, the classification of a given procedure as maintenance or service determines whether a safety interlock is requires.

3.5 TESTING OF PRODUCTS TO ENSURE COMPLIANCE

3.5.1 For each laser product, the manufacturer should keep a written record of tests and procedures which were used to support the manufacturer's classification. Refer to Annex D for the test methods and procedures.

3.5.2 The following aspects should be considered for inclusion:

(a) reported product and labelling;

(b) manner in which the product complies with the standard;

(c) testing program to assure compliance;

(d) testing; and

(e) test equipment used.

3.6 CERTIFICATION OF PRODUCT COMPLIANCE

3.6.1 Certification of product compliance is entrusted to the manufacturer. However, it should be noted that products which are intended for export will be subject to the laws and regulations governing laser products in the countries concerned. To this end, manufacturers should ensure that:

a) the classification is accurate; and

b) written records are kept as to how the classification was arrived at.

3.6.2 It is recommended that the classification is stated on all advertising, operation and service literature (see also labelling requirements in paragraph 3.4.3 above).

3.7 RECORD KEEPING

3.7.1 Records, as specified in sections 3.4, 3.5 and 3.6, should be kept for each laser product for a minimum of five years after the last such product has left the factory.

3.7.2 Each laser products should be identified with a permanent label of plate, bearing the type number and unique serial number, as devised by the manufacturer.

3.7.3 Distribution and history files should be kept which are tractable back to the type and unique serial numbers.

3.7.4 A general correspondence file should also be kept by manufacturer, not necessarily product specific, containing all safety or technical-related enquiries and correspondence, plus the relevant replies.

3.8 REPORTAGE OF ACCIDENTS

3.8.1 At the point of manufacture

All reasonable precautions should be taken to prevent laser radiation exposure to employees, especially if that radiation exceeds the Class 1 limits. Precautions include provision of goggles, shielded enclosure and jigs and fixtures where they can reduce the possible or real risks of exposure. For Class 3B and Class 4 lasers, a Designated Laser Safety Officer should be appointed for each specific type of laser.

3.8.2 During product use or service

If any physical accidents or injuries are reported back from customers or service personnel, the manufacturer should immediately take remedial action with respect to:

(a) repair or replacement of the product concerned;

(b) user and service documentation to warn against future occurrences;

(c) possible design improvements on the product type; and

(d) consideration of product recall.

3.8.3 Reportage

In both the above cases, a brief report should be sent to the Government Laser Safety Officer of the Electrical and Mechanical Services Department of the Government of the Hong Kong Special Administrative Region and where appropriate, the Commissioner for Labour.

3.9 RECALL, REPLACEMENT AND REPAIR

3.9.1 If any single laser or, batch or type of laser products is found to be:

(a) defective respect to safety or function;

(b) non-compliant with the certified classification;

(c) hazardous if used in a particular mode; or

(d) prone to safety failure in the long term;

then all efforts should be made to trace the product(s) affected and organise a plan of remedial action. In order to encompass as many of the products as physically possible, the manufacturer should write to all exporters, importers, distributors, agents and end user that are known, giving the type numbers and serial numbers affected, along with the proposed remedial action.

3.9.2 All expenses relating to the tracing of products, disseminating information and repairs/recalls/replacements should be borne by the manufacturer.

Part 4

Guidance on the Safe Use of Lasers for Display Purposes

4.1 INTRODUCTION

4.1.1 Lasers are often used in entertainment areas to give special visual effects. Organisers and directors of shows or managers of an entertainment area should be aware of the hazards of lasers to eyes of the audience and the performers. Lasers may be used for public display for example in decorations and in advertisement. Employers of such lasers should be aware of the possible hazards to the public. Firms supplying, installing or operating display lasers should be fully conversant with the guidance given in this part and the basic information in Part 1, in order to safeguard the general public from possible laser damage.

4.1.2 This guidance relates only to the special considerations necessary to provide protection against laser and collateral radiation emitted by display laser products during the setting up/alignment or use of such products to provide the required visual effect. For the purpose of this guidance, "display" shall include all entertainment, theatrical, stage, set and decoration applications, advertising promotions and illuminations.

4.1.3 For outdoor/indoor laser displays, organisers and directors of shows or managers of an entertainment area should also be aware of the Advertisement By Laws of the Public Health and Municipal Services Ordinance, the Hong Kong Airport (Control of Obstructions) Ordinance and the Places of Public Entertainment Ordinance, which put limits on the use of such displays.

4.2 DEFINITIONS

The definitions of terms specially pertinent to this guidance are given below:

(a) Authorised

Authorised for the time being in writing by the person in control of the activity.

(b) Display area

That area within which a person, if allowed access, would be exposed to laser radiation, including reflections from targets and scattering materials, in the normal course of operation of a laser effect from a display laser product.

(c) Laser effect

The visual effect produced from the intended use of a display laser product.

(d) Protective equipment

Equipment provided for the use of operators/performers which will attenuate/absorb laser radiation and thus prevent exposure of the eyes and/or skin to levels of laser radiation in excess of the relevant maximum permissible exposure levels.

(e) Trained

Having received relevant instructions and appropriate training to the extent necessary to enable the person concerned to perform the required task in a manner which will provide a safe system of work and eliminate the potential hazard to himself and to others who might be affected by his performance of that required task.

(f) Visible radiation light

Any radiation capable of causing a visual sensation directly. Note : in these guidelines, this is taken to mean electromagnetic radiation for which the wavelengths of the monochromatic components lie between 400 nm to 700 nm.

4.3 GUIDELINES

4.3.1 General requirement

Each display laser product should be so designed, constructed and maintained as to be safe when properly used. In this context due regard should be paid to IEC 60825-1:2001 relating to requirements for radiation safety of laser products and equipment classification.

4.3.2 Notification

Prior to the public use of any display laser product, the operator of the laser system should supply sufficient information to the Government Laser Safety Officer of the Electrical and Mechanical Services Department for assessing the foreseeable hazards. This information should include:

(a) sketches, calculations, and radiometric measurement data, etc, to demonstrate that the system can be used safely and without risks to health;

(b) written information regarding the security arrangements; and

(c) conditions under which the laser operation will be shut down.

4.3.3 Display laser information

Annex K gives an outline of the type of information which should be supplied for the full evaluation of the potential hazards.

4.3.4 Emission of invisible radiation

The emission of any laser and collateral radiation outside the spectral range 400 nm – 700 nm should be kept to the minimum that is reasonably practicable and in any event should not exceed the accessible emission limits for Class 1 laser products.

4.3.5 Emission of visible radiation

The power output from any display laser product in the spectral range 400 nm – 700 nm should be kept to the minimum necessary to produce the desired effect.

4.3.6 Mounting of the laser systems

Each display laser product and all associated optical components, mirrors, etc, should be rigidly mounted to prevent unintended movements or accidental misalignment.

4.3.7 Use of beam stops

Laser apertures shall be masked using a material made of black-painted steel or aluminum plate, which is sufficiently robust to withstand direct exposure to the laser radiation for extended period of time. The mask shall be positioned to confine the projections to the intended directions and to prevent errant laser radiation.

4.3.8 Control against unauthorised use

All display laser products should be provided with a key-operated ON/OFF switch to secure the laser against unauthorised use.

4.3.9 Demarcation of laser display area

Each effect from a display laser product should take place within a predetermined and defined display area. The emission of laser radiation should be terminated automatically immediately when the laser effect / beam leaves the boundaries of this display area.

4.3.10 Siting of laser control console

The entire laser performance should be controlled and monitored by trained operators who should be stationed at all time at the control panel (incorporating the emergency stop controls). The control console for each display laser product should be secure and sited in such a position that the operator is able to view the whole of the display area. Where this is not practicable, alternative effective arrangements should be made whereby the operator is able to assess the situation and be aware of any malfunction, etc.

4.3.11 Emergency cut-off for laser radiation

All display laser products should be provided with one or more readily accessible controls which will immediately terminate the emission of any laser radiation. In the event that a laser system is not required to be under the continuous supervision or control of an operator, a person on site should be designated to be responsible for the immediate termination of the laser radiation in case of equipment malfunction, audience unruliness or other unsafe conditions.

4.3.12 Marking of area boundaries

Any area where the levels of laser radiation exceed the accessible emission limit for Class 1 laser products should be clearly identified, appropriate warning notices posted and barriers erected to prevent the entry of unauthorised persons. Entry into these areas should be undertaken only by authorised persons if necessary and wearing the appropriate protective equipment.

4.3.13 Permissible exposure levels for audience/members of the public

The level of laser and collateral radiation should not exceed the maximum permissible exposure level at any point where the public is permitted during the display. Radiation includes reflections from targets and scattering materials.

4.3.14 Permissible exposure levels for operators/performers

The accessible exposure level of laser radiation to operators/performers should not exceed the maximum permissible exposure if such radiation is intended to be viewed by them in order to perform their functions. In the event that such radiation is not intended to be viewed by them then the accessible exposure level should not exceed the accessible exposure limit specified for Class 3R laser products.

4.3.15 Use of scanning devices

The use of scanning devices, including mirror balls, should incorporate a means which shall automatically prevent exposure to levels in excess of those specified in paragraphs 4.3.13 and 4.3.14 in the event of scan failure or other failure.

4.3.16 Operation of laser system(s)

(a) Unsupervised — in the event that a display laser product does not operate under the direct supervision of an authorised trained operator, the laser radiation levels must not exceed the accessible emission limit specified for Class 2 laser products at any point less than 6m above any surface upon which a person in the audience is permitted to stand during the display.

(b) Supervised – Laser light shows or displays which do not meet (a) above shall be operated at all times under the direct supervision or control of an authorised trained operator who shall maintain constant surveillance of the laser effect and immediately terminate the emission of the laser radiation in the event of equipment malfunction, audience unruliness or other unsafe conditions.

(c) In addition, for both unsupervised and supervised laser light shows and displays, laser radiation levels to which human access can be gained must not exceed the limits of Class 1 at any point:

    (i) less than 3m above any surface upon which the audience/general public is permitted to stand; or

    (ii) less than 2.5m in lateral separation from any position where a person in the audience/general public is permitted during the display. (see paragraph 4.3.20 for additional special considerations for the outdoor use of laser).

4.3.17 Setting up/Alignment of laser systems

The following precautions should be taken:

(a) The setting up/alignment of laser systems should only be undertaken by a trained laser operator.

(b) Only those persons required to perform relevant functions should be present during the alignment/setting up of the systems.

(c) The accessible emission level of laser radiation should be reduced to the minimum practicable level and in any event should not exceed the accessible emission limit for Class 1 or Class 2 laser products.

(d) Where necessary for the protection of those employed, appropriate protective equipment should be worn during the alignment/setting up of the laser equipment.

(e) Where practicable, display areas should be clearly demarcated by warning signs and, preferably, sealed off by barriers during setting up procedures.

4.3.18 Determination of laser radiation exposure levels

The accessible emission levels of laser radiation should be measured and/or calculated by the operator at all positions where the audience, general public, operators or performers may be exposed to the primary beam(s) or to reflections from targets and scattering materials.

4.3.19 Functional checks prior to public operation of the laser display

A functional check should be made to all safety devices, interlocks, etc, which have been provided to ensure the safety of persons prior to each public use of a display laser product.

4.3.20 Venue consideration

(a) Indoor displays

(i) Mezzanine and raised floors, balconies and staircases are all areas where people may be exposed to laser radiation. Careful hazard assessment of beam paths and accurate laser masking are therefore important.

(ii) Mirrors should be securely mounted and inaccessible to unauthorized people. Mirrors that would shine hazardous emissions into public areas if misaligned should be masked to restrict reflection angles to a range that minimizes this risk.

(b) Open air displays

(i) The security and robustness of external "targets" is particularly important in open-air displays because they are affected by weather, vibrations from traffic and sometimes, deliberate interference and vandalism. At typical outdoor event projection distances, even small misalignment of external optical components or of the laser beam itself can result in a grossly mistargeted hazardous emission.

(ii) It should never be assumed that buildings, roofs and walkways etc. close to or within the display area are unoccupied; people may appear unexpectedly.

(iii) Care should be taken to avoid reflection hazards from objects such as lamp posts, scaffolding, glazed areas, stretches of water, wet surfaces and objects members of the audience may unintentionally place in laser emissions, e.g. reflective balloons. If a beam is to be transmitted from a glazed booth or through a window of a building, special precautions should be taken to eliminate hazardous reflections. Wherever possible windows, through which a beam is to be projected, should be secured open or, better still, removed.

(iv) As a general rule, it is a good practice to ensure that emissions are projected at angles below the horizontal and terminated within the area over which the organizer has control. If this is impractical, emissions may be projected to the skyward. However, unexpected laser emission may dazzle or disorientate aircraft pilots. The Civil Aviation Department should be consulted for advice before an outdoor display is allowed to take place.

(v) Where display laser products are used outdoors, consideration should be given and adequate safeguards adopted for those persons liable to view the beam directly within the nominal optical hazard distance and also those who might view the beam or its reflections using optical aids. In this context special consideration should be given to the hazards that the use of a display laser product might present to traffic movements including those by air, sea, harbour and road.

4.3.21 Viewing using optical Aids

Practicable advice should be given to the audience/general public NOT to view laser displays with additional viewing aids other than prescription lens.

Annexes

Annex A

Abstracted from IEC 60825-1:2001

MEDICAL CONSIDERATIONS

Anatomy of the eye

A.1 Figure A.1 (a) is a diagram of the external features of a left eye. The gap between the overlying lids limits the seen area of the eye to an almond shape. The main features of the eye are labelled, and dotted lines and arrow heads relate them to the section through the eye, which is shown in Figure A.1 (b).

A.2 Figure A.1 (b) is a diagram of a horizontal section of a left eye. The eye is divided into two parts, the front or anterior chamber being bounded by the cornea, the iris and lens; and the back or posterior eye cup, which is bounded by the retina, and contains the gel-like vitreous humour.

A.3 Figure A.1 (c) is a diagram of the inside of an intact left eye as seen through an ophthalmoscope. This instrument directs a beam of light through the pupil and illuminates the inside of the eye and so allows it to be seen. The picture so viewed is referred to as the fundas. It looks reddish, but the major retinal vessels can be clearly seen. Other prominent features are the whitish optic disc, and the fovea. The fovea is a small depression in the retinal surface which may be more pigmented than the surrounding retina and is the area of most acute vision. The fovea is the centre of the macula; the macula is responsible for detailed vision.

A.4 Figure A.1 (d) is a diagram of the magnified structure of the retina (see

Figure A.1 (b)). The retina consists of a series of layers of nerve cells that overlie the photosensitive rods and cone cells; light falling on the retinal surface has to pass through the layers of nerve cells before it reaches the photosensitive cells. Underneath the layer of rods and cones is a layer called the pigment epithelium, which contains a browny black pigment called melanin; beneath this is a layer of fine blood vessels, the choriocapillaris. The final absorbing layer is the choroid, which contains both pigmented cells and blood vessels.

A.5 Figure A.1 (e) is a diagram of the magnified structure of the foveal region. Here only cones are present. The nerve cells are displaced radially away from this area of most acute vision. The macular pigment, which absorbs strongly from 400 to 500 nm, is located in the fiber layer of Henle.

The effects of laser radiation on biological tissues

A.6 The mechanism by which laser light induces damage is similar for all biological systems and may involve thermal, thermo-acoustic transient and photochemical processes. The degree to which any of these mechanisms is responsible for damage may be related to certain physical parameters of the irradiating source, the most important of which are wavelength, pulse duration, image size, irradiance, and radiant exposure.

A.7 In general terms, in supra-threshold exposures the predominating mechanism is broadly related to the pulse duration of the exposure. Thus, in order of increasing pulse duration, the predominant effects in the following time domains are: nanosecond and sub-nanosecond exposures, acoustic transients; from 1 ms to several seconds, thermal effects; and in excess of 10 s, photochemical effects.

A.8 Laser radiation is distinguished from most other known types of radiation by its beam collimation. This, together with an initial high energy content, results in excessive amounts of energy being transmitted to biological tissues. The primary event in any type of laser radiation damage to a biological system is the absorption of radiation by that system.

A.9 Absorption occurs at an atomic or molecular level and is a wavelength specific process. Therefore, it is the wavelength that determines which tissue a particular laser is liable to damage. When sufficient light energy has been absorbed by a system its component molecules experience an increased vibration, and this leads to an increase in temperature. Most laser damage is due to the heating of the absorbing tissue or tissues. This thermal damage is usually confined to a limited area extending to either side of the energy absorbing layer, and centered on the irradiating beam. Cells within this area show burn characteristics, and tissue damage primarily results from denaturation of protein. As indicated above, the occurrence of secondary damage mechanisms in laser impacts can be related to the time course of the tissue heating reaction, which is directly related to the pulse duration of the laser (see Figure A.2) and the period of cooling. Thermochemical reactions occur during both the heating and cooling period, giving rise to a spot-size dependence of thermal injury. If a CW or long–pulse laser system is directed on to a tissue, then, because of conduction, the area of the system experiencing a raised temperature is progressively increased. This spreading thermal front results in an expanding damage zone as more and more cells are raised above their thermal tolerance. The beam image size is also of great importance as the degree of peripheral spread due to conduction is a function of the size as well as the temperature of the initial area of tissue heating. This type of thermal lesion is commonly seen on exposure to CW or long-pulsed lasers, but also occurs with short pulses. For irradiated spot sizes of the order of 1 mm to 2 mm or less, the radial heat flow leads to a spot-size dependence of injury.

A.10 On the other hand, damaging effects can be the direct result of specific molecular absorption of a given light. This process is created by absorption of given light energy. Rather than releasing the energy, however, the species undergoes a chemical reaction unique to its excited state. This photochemical reaction is believed to be responsible for damage at low levels of exposure. By this mechanism, some biological tissues such as the skin, the lens of the eye, and in particular the retina may show irreversible changes induced by prolonged exposure to moderate levels of UV radiation and short-wavelength light. Such photochemically induced changes may result in damage to a system if the duration of irradiation is excessive, or if shorter exposures are repeated over prolonged periods. Some of the photochemical reactions initiated by laser exposure may be abnormal, or exaggerations of normal processes. Photochemical reactions generally follow the Law of Bunsen and Roscoe, and for durations of the order of 1 h to 3 h or less (where repair mechanisms come into play), the threshold expressed as a radiant exposure is constant over a wide range of exposure durations. The spot-size dependence, as occurs with thermal effects due to heat diffusion, does not exist.

A.11 Short-pulsed Q-switched or mode-locked lasers may give rise to tissue damage with a different combination of induction mechanisms. Energy is delivered to the biological target in a very short time and hence a high irradiance is produced. The target tissues experience such a rapid rise in temperature that the liquid components of their cells are converted to gas. In most cases, these phase changes are so rapid that they are explosive and the cells rupture. The pressure transients so produced result in an annular blast zone around the burn center. Similar pressure transients may result from thermal expansion and both may also result in shearing damage to tissues remote from the absorbing layers by bulk physical displacement. At sub-nanosecond exposures, self-focusing of the ocular media further concentrates laser energy from a collimated beam and further lowers the threshold between approximately 10 ps and 1 ns. Furthermore, other non-linear optical mechanisms appear to play a role in retinal injury in the sub-nanosecond region.

A.12 All of the above-described damage mechanisms have been shown to operate in the retina and are reflected in the breakpoints or changes of slope in the safe exposure levels described in this standard.

Hazards to eye

A.13 A brief description of the anatomy of the eye is given in paragraphs A.1 to A.5 above. The eye is specially adapted to receive and transduce optical radiation. The absorption properties of the eye with respect to radiations of different wavelengths are shown in Figure A.3 and the associated pathological effects caused by excessive exposure are summarized in Table A.1. Therefore, lasers emitting ultraviolet and far infra-red radiation represent a corneal hazard whereas lasers emitting radiation in the visible and near infra-red wavelengths represent a retinal hazard.

A.14 Visible and near infra-red lasers are a special hazard to the eye because the very properties necessary for the eye to be an effective transducer of light result in high radiant exposure being presented to highly pigmented tissues. The increase in irradiance from the cornea to the retina is approximately the ratio of the pupil area to that of the retinal image. This increase arises because the light that has entered the pupil is focused to a 'point' image on the retina. The pupil is a variable aperture but the diameter may be as large as 7 mm when maximally dilated in the young eye. The retinal image corresponding to such a pupil may be between 10 μm and 20 μm in diameter. With intra-ocular scattering and corneal aberrations considered, the increase in irradiance between the cornea and the retina is of the order 2 X 10^5. If an increase of 2 X 10^5 is assumed, a 50 Wm^{-2} beam on the cornea becomes 1 X 10^7 W m^{-2} on the retina. In this standard a 7 mm pupil is considered as a limiting aperture as this is a worst case condition and is derived from figures obtained from the young eye where pupillary diameters of this order have been measured. An exception to the assumption of a 7 mm pupil was applied in the derivation of exposure limits to protect against photoretinitis whilst viewing bright visible (400 nm to 700 nm) laser sources for periods in excess of 10 s. In this latter situation, a 3 mm pupil was assumed as a worst-case condition; however, a 7 mm irradiance averaging aperture for measurement was still considered appropriate due to physiological movements of the pupil in space. Hence, AELs for durations greater than 10 s are still derived for a 7 mm aperture.

A.15 If an intense beam of laser light is brought to a focus on the retina, only a small fraction of the light (up to 5%) will be absorbed by the visual pigments in the rods and cones. Most of the light will be absorbed by the pigment called melanin contained in the pigment epithelium. (In the macular region some energy in the 400 nm to 500 nm range will be absorbed by the macular pigment). The absorbed energy will cause local heating and will burn both the pigment epithelium and the adjacent light-sensitive rods and cones. This burn or lesion may result in a loss of vision. Photochemical injuries, although non-thermal, are also localized in the pigment epithelium.

A.16 Depending on the magnitude of the exposure, such a loss of vision may or may not be permanent. A visual decrement will usually be noted subjectively by an exposed individual only when the central or foveal region of the macula is involved. The fovea, the pit in the centre of the macula, is the most important part of the retina as it is responsible for sharpest vision. It is the portion of the retina that is used "to look right at something". This visual angle subtended by the fovea is approximately equal to that subtended by the moon. If this region is damaged, the decrement may appear initially as a blurred white spot obscuring the central area of vision; however, within two or more weeks, it may change to a black spot. Ultimately, the victim may cease to be aware of this blind spot (scotoma) during normal vision. However, it can be revealed immediately on looking at an empty visual scene such as a blank sheet of white paper. Peripheral lesions will only be registered subjectively when gross retinal damage has occurred. Small peripheral lesions will pass unnoticed and may not even be detected during a systematic eye examination.

A.17 In the wavelength range from 400 nm to 1400 nm, the greatest hazard is retinal damage. The cornea, aqueous humour, lens and vitreous humor are transparent for radiation of these wavelengths. In the case of a well-collimated beam, the hazard is virtually independent of the distance between the source of radiation and the eye, because the retinal image is assumed to be a diffraction-limited spot of around 10 μm to 20 μm diameter. In this case, assuming thermal equilibrium, the retinal zone of hazard is determined by the limiting angular subtense α_{min}, which generally corresponds to retinal spot of approximately 25 μm in diameter.

A.18 In the case of an extended source, the hazard varies with the viewing distance between the source and the eye, because whilst the instantaneous retinal irradiance only depends on the source's radiance and on the lens characteristics of the eye, thermal diffusion of energy from larger retinal images is less efficient, leading to a retinal spot-size dependence for thermal injury which does not exist for photochemical injury (dominating only in the 400 nm to 600 nm spectral region). In addition, eye movements further spread the absorbed energy for CW laser exposures, leading to different dependencies of risk for differing retinal image sizes.

A.19 In the derivation of limits for ocular exposure in the retinal hazard region, correction factors for eye movements were only applied for viewing durations exceeding 10 s. Although physiological eye movements known as saccades do spread the absorbed energy in minimal retinal images (of the order of 25 μm or less) within the 0.1 s to 10 s time regime, the limits provide a desired added safety factor for this viewing condition. At 0.25 s, the mean retinal spot illuminated is approximately 50 μm. By 10 s, the illuminated retinal zone becomes approximately 75 μm and the added safety factor for the minimal image condition becomes 1.7 over a stabilized eye, with the spot-size dependence taken into account. By 100 s, it is rare to achieve an illuminated zone (measured at 50 % points) as small as 135 μm leading to an additional safety factor of 2 - 3 or more for the minimal image condition.

A.20 The data from eye-movement studies and retinal thermal injury studies were combined to derive a break-point in viewing time T_2 at which eye movements compensated for the increased theoretical risk of thermal injury for increased retinal exposure durations if the eye were immobilized. Because the thermal injury threshold expressed as radiant power entering the eye decreases as the exposure duration t raised to the -0.25 power (i.e. a reduction of only 44% per tenfold increase in duration), only moderate increases in the exposed retinal area will compensate for the increased risk for longer viewing times. The ever-increasing retinal area of irradiation resulting from greater eye movements with increased viewing time takes longer to compensate for the reduced impact of thermal diffusion in larger extended sources. Thus, for increasing angular subtense α, the break-point T_2 increases from 10 s for small sources to 100 s for larger sources. Beyond 100 s there is no further increase in risk of thermal injury for small and intermediate size images. The specification of limits and measuring conditions attempt to follow these variables with some simplification leading to a conservative determination of risk. It is conservatively assumed that retinal thermal injury thresholds vary inversely with retinal image size (stabilized) between approximately 25 μm to 1 mm (corresponding to angular sizes of 1 μm to 59 mrad), whilst beyond 1.7 mm (corresponding to angular sizes greater than 100 mrad), there is no spot-sized dependence.

A.21 For photochemically induced retinal injury there is no spot size dependence for a stabilized image. Unlike thermal injury mechanism, the thresholds for photochemical injury are highly wavelength dependent and are exposure dose dependent, i.e. the thresholds decrease inversely with the lengthening of exposure time. Studies of photochemical retinal injury from welding arcs subtending angles of the order of 1 mrad to 1.5 mrad showed typical lesion sizes of the order of 185 μm to 200 μm (corresponding to visual angles of 11 mrad to 12 mrad), clearly showing the influence of eye movements during fixation; these and other studies of eye movements during fixation led to the derivation of MPEs to protect against photochemical retinal injury. These studies also led to MPE irradiance to be specified as being averaged over 11 mrad for exposure durations between 10 s and 100 s. Hence, sources with an angular subtense α less than 11 mrad were treated equally with "point-type" sources, and the concept of α_{min} was extended to CW laser viewing. This approach was not strictly correct, as an irradiance measurement of an 11-mrad source is not equivalent to irradiance averaging over a field of view (γ) of 11 mrad unless the source had a rectangular ("top-hat") radiance distribution. Hence, distinction is made between angular subtense of a source and irradiance averaging for photochemical MPE values. For viewing times in excess of approximately 30 s to 60 s, the saccadic eye motion during fixation is generally overtaken by behavioural movements determined by visual task, and it is quite unreasonable to assume that a light source would be imaged solely in the fovea for durations longer than 100 s. For this reason, the angle of acceptance γ_p is increased linearly with the square-root of t. The minimal angular subtense α_{min} correctly remains at the reference angle of 1.5 mrad for all exposure durations used in thermal retinal hazard evaluation. However, for photochemical retinal hazard assessment, the concept is actually different, as the angle γ_p is a linear angle of acceptance for the measurement of irradiance, and this is important to apply only for extended sources greater than approximately 11 mrad.

A.22 In the case of a "point-type", diverging-beam source, the hazard increases with decreasing distance between the beam waist and the eye. The reason is that, with decreasing distance, the collected power increases, while the size of the retinal image can be assumed to remain nearly diffraction-limited for true laser sources down to a distance as close as 100 mm (due to the accommodation capabilities of the eye). The greatest hazard occurs at the shortest accommodation distance. With further reduced distance, the hazard to the unaided eye is also reduced, as there is a rapid growth of the retinal image and a corresponding reduction of the irradiance, even though more power may be collected. To simulate the risk of optically aided viewing of a collimated beam with binoculars or a telescope, the closest distance of approach of 2 m with a 50-mm aperture was assumed based upon the closest distance for clear viewing.

A.23 For the purpose of this publication, the shortest accommodation distance of the human eye is set to 100 mm at all wavelengths from 400 nm to 1400 nm. This was chosen as a compromise, because all but a few young people and very few myopics cannot accommodate their eyes to distances of less than 100 mm. This distance may be used for the measurement of irradiance in the case of intrabeam viewing (see Table C.1 of Annex C)

A. 24 For wavelengths of less than 400 nm or more than 1400 nm, the greatest hazard is damage to the lens or the cornea. Depending on the wavelength, optical radiation is absorbed preferentially or exclusively by the cornea or the lens (see table A.1). For diverging-beam sources (extended or point-type) of these wavelengths, short distances between the source and the eye should be avoided.

A.25 In the wavelength range from 1500 nm to 2600 nm, radiation penetrates into the aqueous humour. The heating effect is therefore dissipated over a greater volume of the eye, and the MPEs are increased for exposures less than 10 s. The greatest increase in the MPEs occurs for very short pulse durations and within the wavelength range of 1500 nm to 1800 nm where the absorbing volume is greatest. At times greater than 10 s, heat conduction redistributes the thermal energy so that the impact of the penetration depth is no longer significant.

Skin Hazards

A.26 In general terms, the skin can tolerate a great deal more exposure to laser beam energy than can the eye. The biological effect of irradiation of skin by lasers operating in the visible and infra-red spectral regions may vary from a mild erytheme to severe blisters. An ashen charring is prevalent in tissues of high surface absorption following exposure to Q-switched type lasers emitting very short pulses. This may, or may not, be followed by erytheme.

A.27 The pigmentation, ulceration and scarring of the skin and damage of underlying organs may occur from extremely high irradiance. Latent or cumulative effects of laser radiation have not been found prevalent. However, some limited research has suggested that under special conditions small regions of human tissue may be sensitized by repeating local exposures with the result that the exposure level for minimal reactions is changed and the reactions in the tissues are more severe for such low level exposures.

A.28 In the wavelength range 1500 nm to 2600 nm, biological threshold studies indicate that the risk of skin injury follows a similar pattern to that of the eye. For exposures up to 10 s, the MPE is increased within this spectral range.

Figure A.1 Anatomy of the eye

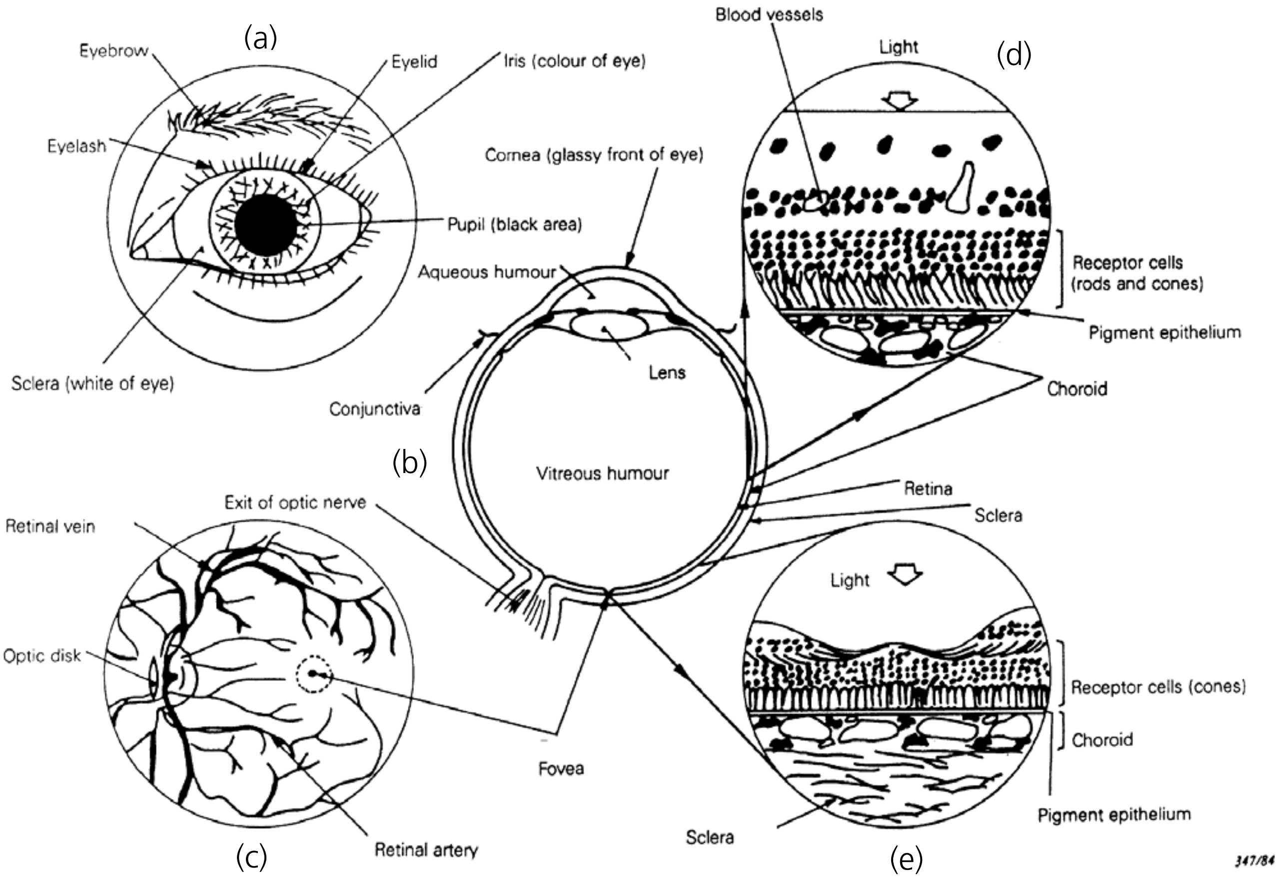
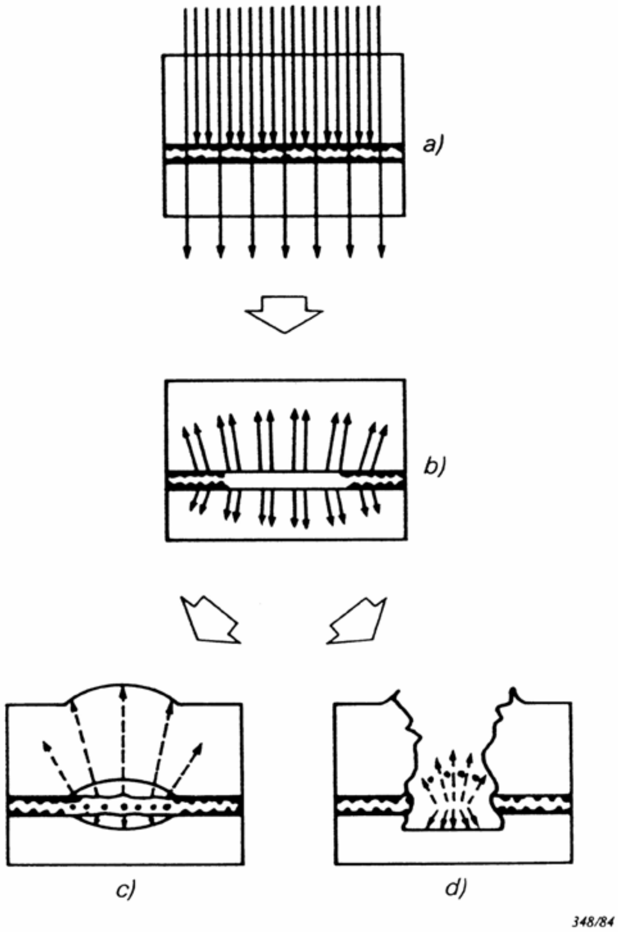


Figure A.2 Laser-induced damage in biological systems



a) Laser energy is absorbed by the system.

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

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

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

Figure A.3 Absorption properties of the eye with respect to radiations of different wavelengths.

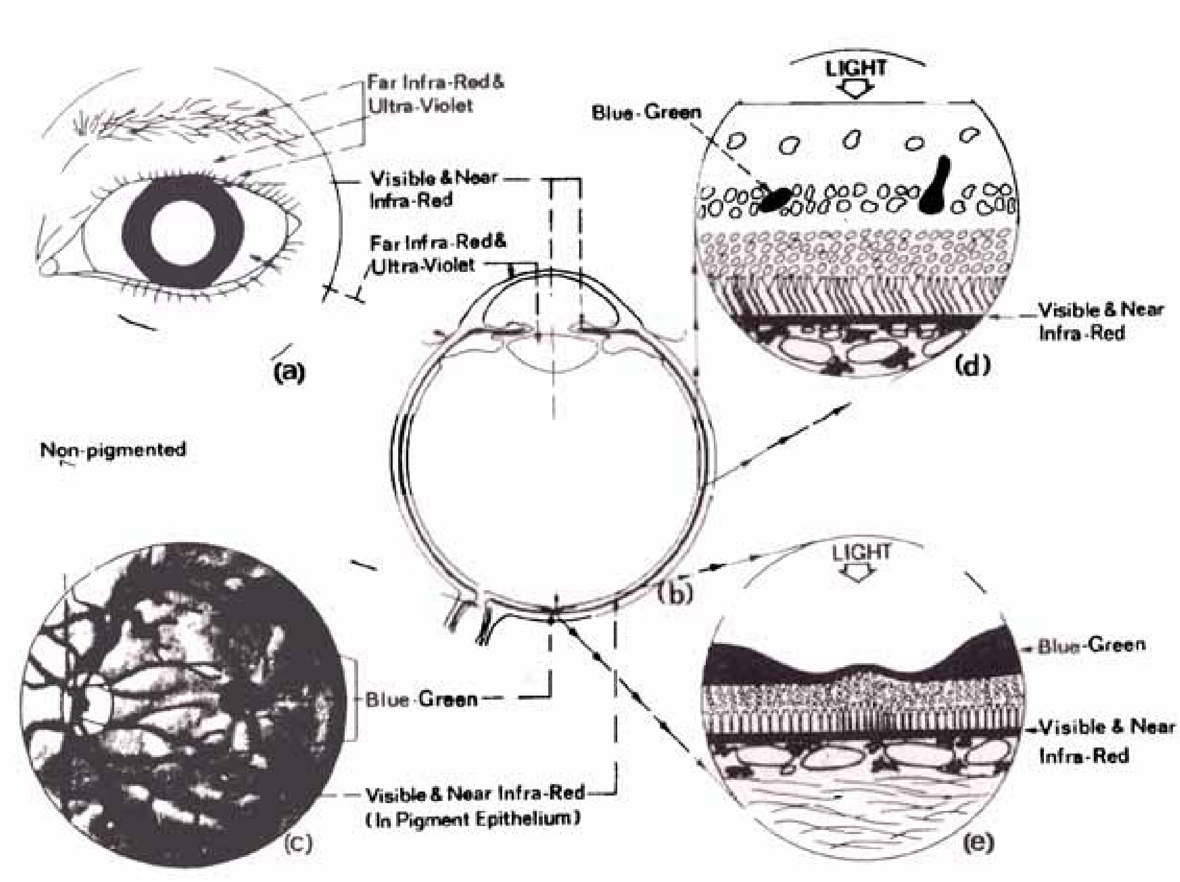


Table A.1 – Summary of pathological effects associated with excessive exposure to light

<table>
<tr><th>CIE [a] Spectral region [b]</th><th>Eye</th><th colspan="2">Skin</th></tr>
<tr><td>Ultra-violet C
(180 nm to 280 nm)</td><td rowspan="2">Photokeratitis</td><td rowspan="2">Erythema (sunburn)
Accelerated skin ageing process
Increased pigmentation</td><td rowspan="2"></td></tr>
<tr><td>Ultra-violet B
(280 nm to 315 nm)</td></tr>
<tr><td>Ultra-violet A
(315 nm to 400 nm)</td><td>Photochemical cataract</td><td rowspan="2">Pigment darkening
Photosensitive reactions</td><td rowspan="5">Skin burn</td></tr>
<tr><td>Visible
(400 nm to 780 nm)</td><td>Photochemical and thermal retinal injury</td></tr>
<tr><td>Infra-red A
(780 nm to 1400 nm)</td><td>Cataract, retinal burn</td><td rowspan="3"></td></tr>
<tr><td>Infra-red B
(1.4 μm to 3.0 μm)</td><td>Aqueous flare, cataract, corneal burn</td></tr>
<tr><td>Infra-red C
(3.0 μm to 1 mm)</td><td>Corneal burn only</td></tr>
<tr><td colspan="4">[a] “CIE” stands for “International Commission on Illumination”

[b] The spectral regions defined by the CIE are short-hand notations useful in describing biological effects and may not agree perfectly with spectral breakpoints in the MPE tables.</td></tr>
</table>

MAXIMUM PERMISSIBLE EXPOSURE (MPE) LEVELS

Table B.1 – Maximum permissible exposure (MPE) at the cornea for direct exposure to laser radiation [a, b, c]

<table>
<tr><th>Exposure time t in s
Wavelength λ in nm</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to 10^{-7}</th><th>10^{-7} to 1.8×10^{-5}</th><th>1.8×10^{-5} to 5×10^{-5}</th><th>5×10^{-5} to 1×10^{-3}</th><th>1×10^{-3} to 10</th><th>10 to 10^2</th><th>10^2 to 10^3</th><th>10^3 to 10^4</th><th>10^4 to 3×10^4</th></tr>
<tr><td>180 to 302.5</td><td colspan="2" rowspan="3">3×10^{10} W.m^{-2}</td><td colspan="9">30 J.m^{-2}</td></tr>
<tr><td>302.5 to 315</td><td colspan="5">(t ≤ T_1) C_1 J.m^{-2}
C_2 J.m^{-2} (t > T_1)</td><td colspan="4">C_2 J.m^{-2}</td></tr>
<tr><td>315 to 400</td><td colspan="5">C_1 J.m^{-2}</td><td colspan="2">10^4 J.m^{-2}</td><td colspan="2">10 W.m^{-2}</td></tr>
<tr><td rowspan="4">400 to 700[d]</td><td rowspan="4">1.5×10^{-4} C_6 J.m^{-2}</td><td rowspan="4">2.7×10^4 $t^{0.75} C_6$ J.m^{-2}</td><td colspan="2" rowspan="4">5×10^{-3} C_6 J.m^{-2}</td><td colspan="2" rowspan="4">18 $t^{0.75} C_6$ J.m^{-2}</td><td rowspan="3">400 to 600 nm[d]</td><td colspan="4">Retinal photochemical hazard</td></tr>
<tr><td>100 C_3 J.m^{-2} using γ_p = 11 mrad</td><td colspan="2">1 C_3 W.m^{-2} using γ_p = 1.1 $t^{0.5}$ mrad</td><td>1 C_3 W.m^{-2} using γ_p = 110 mrad</td></tr>
<tr><td colspan="4">AND[d]</td></tr>
<tr><td>400 to 700 nm[d]</td><td colspan="4">Retinal thermal hazard
α ≤ 1.5 mrad: 10 W.m^{-2}
α > 1.5 mrad: 18 C_6 $T_2^{-0.25}$ W.m^{-2}
(t > T_2)
(t ≤ T_2)
18 $t^{0.75} C_6$ J.m^{-2}</td></tr>
<tr><td>700 to 1050</td><td>1.5×10^{-4} $C_4 C_6$ J.m^{-2}</td><td>2.7×10^4 $t^{0.75}$ $C_4 C_6$ J.m^{-2}</td><td colspan="2">5×10^{-3} C_4 C_6 J.m^{-2}</td><td colspan="3">18 $t^{0.75}$ $C_4 C_6$ J.m^{-2}</td><td colspan="4" rowspan="2">α ≤ 1.5 mrad: 10 $C_4 C_7$ W.m^{-2}
α > 1.5 mrad: 18 $C_4 C_6$ C_7 $T_2^{-0.25}$ W.m^{-2}
(t > T_2)
(t ≤ T_2)
18 $t^{0.75} C_4$ C_6 C_7 J.m^{-2}</td></tr>
<tr><td>1050 to 1400</td><td>1.5×10^{-3} $C_6 C_7$ J.m^{-2}</td><td>2.7×10^5 $t^{0.75} C_6$ C_7 J.m^{-2}</td><td colspan="3">5×10^{-2} C_6 C_7 J.m^{-2}</td><td colspan="2">90 $t^{0.75}$ $C_6 C_7$ J.m^{-2}</td></tr>
<tr><td>1400 to 1500</td><td colspan="2">10^{12} W.m^{-2}</td><td colspan="4">10^3 J.m^{-2}</td><td>5600 $t^{0.25}$ J.m^{-2}</td><td colspan="4" rowspan="4">1000 W.m^{-2}</td></tr>
<tr><td>1500 to 1800</td><td colspan="2">10^{13} W.m^{-2}</td><td colspan="5">10^4 J.m^{-2}</td></tr>
<tr><td>1800 to 2600</td><td colspan="2">10^{12} W.m^{-2}</td><td colspan="4">10^3 J.m^{-2}</td><td>5600 $t^{0.25}$ J.m^{-2}</td></tr>
<tr><td>2600 to 10^6</td><td colspan="2">10^{11} W.m^{-2}</td><td>100 J.m^{-2}</td><td colspan="4">5600 $t^{0.25}$ J.m^{-2}</td></tr>
</table>

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

[b] The MPEs for exposure times below 10^{-9} s and for wavelengths less than 400 nm and greater than 1400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPEs for exposure times below 10^{-13} s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

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

[d] In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure must not exceed either limit applicable. Normally photochemical hazard limits only apply for exposure durations greater than 10 s; however, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1.5 mrad and 82 mrad, the dual photochemical hazard limit of 100 C_3Jm^{-2} shall be applied for exposures greater than or equal to 1s.

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

Wavelength λ nm \ Exposure time t s	$< 10^{-9}$	10^{-9} to 10^{-7}	10^{-7} to 10^{-3}	10^{-3} to 10	10 to 10^{3}	10^{3} to 3×10^{4}
180 to 302.5	3×10^{10} W.m^{-2}	30 J.m^{-2}				
302.5 to 315		C_1 J.m^{-2} ($t \leq T_1$) / C_2 J.m^{-2} ($t > T_1$)			C_2 J.m^{-2}	
315 to 400		C_1 J.m^{-2}			10^{4} J.m^{-2}	10 W.m^{-2}
400 to 700	2×10^{11} W.m^{-2}	200 J.m^{-2}		$1.1 \times 10^{4}\, t^{0.25}$ J.m^{-2}	2000 W.m^{-2}	
700 to 1400	$2 \times 10^{11}\, C_4$ W.m^{-2}	$200 C_4$ J.m^{-2}		$1.1 \times 10^{4}\, C_4 t^{0.25}$ J.m^{-2}	$2000 C_4$ W.m^{-2}	
1400 to 1500	10^{12} W.m^{-2}	10^{3} J.m^{-2}		$5600 t^{0.25}$ J.m^{-2}	1000 W.m^{-2} [3)]	
1500 to 1800	10^{13} W.m^{-2}	10^{4} J.m^{-2}				
1800 to 2600	10^{12} W.m^{-2}	10^{3} J.m^{-2}		$5600 t^{0.25}$ J.m^{-2}		
2600 to 10^{6}	10^{11} W.m^{-2}	100 J.m^{-2}		$5600 t^{0.25}$ J.m^{-2}		

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

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

3) For exposed skin areas greater than 0.1 m^2, the MPE is reduced to 100 W.m^{-2}. Between 0.01 m^2 and 0.1 m^2, the MPE varies inversely proportional to the irradiated skin area.

Annex C

Abstracted from IEC 60825-1:2001

ACCESSIBLE EMISSION LIMITS FOR CLASSIFICATION OF LASERS

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

<table>
<tr><th>Exposure time t in s
Wavelength λ in mm</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to 10^{-7}</th><th>10^{-7} to 1.8×10^{-5}</th><th>1.8×10^{-5} to 5×10^{-5}</th><th>5×10^{-5} to 1×10^{-3}</th><th>1×10^{-3} to 0.35</th><th>0.35 to 10</th><th>10 to 10^2</th><th>10^2 to 10^3</th><th>10^3 to 10^4</th><th>10^4 to 3×10^4</th></tr>
<tr><td>180 to 302.5</td><td colspan="2">3×10^{10} W.m^{-2}</td><td colspan="10">30 J·m^{-2}</td></tr>
<tr><td>302.5 to 315</td><td colspan="2" rowspan="2">2.4×10^4 W</td><td colspan="6">($t \leq T_1$)
7.9×10^{-7} C_1 J
7.9×10^{-7} C_2 J
($t > T_1$)</td><td colspan="4">7.9×10^{-7} C_2 J</td></tr>
<tr><td>315 to 400</td><td colspan="6">7.9×10^{-7} C_1 J</td><td colspan="2">7.9×10^{-3} J</td><td colspan="2">7.9×10^{-6} W</td></tr>
<tr><td rowspan="5">400 to 700[d]</td><td rowspan="5">5.8×10^{-9} C_6J</td><td rowspan="5">1.0 $t^{0.75}$ C_6J</td><td colspan="2" rowspan="5">2×10^{-7} C_6J</td><td colspan="3" rowspan="5">7×10^{-4} $t^{0.75}$ C_6J</td><td rowspan="3">400 to 600 nm[d]</td><td colspan="4">Retinal photochemical hazard</td></tr>
<tr><td>3.9×10^{-3} C_3 J using γ_p = 11 mrad</td><td colspan="2">3.9×10^{-5} C_3 W using $\gamma_p = 1.1\ t^{0.5}$ mrad</td><td>3.9×10^{-5} C_3 W using γ_p = 110 mrad</td></tr>
<tr><td colspan="4">AND[d]</td></tr>
<tr><td rowspan="2">400 to 700 nm[d]</td><td colspan="4">Retinal thermal hazard</td></tr>
<tr><td colspan="4">α ≤1.5 mrad: 3.9×10^{-4}W
α > 1.5 mrad: 7×10^{-4} C_6 $T_2^{-0.25}$ W
($t > T_2$)
($t \leq T_2$)
7×10^{-4} $t^{0.75}$ C_6 J</td></tr>
<tr><td>700 to 1 050</td><td>5.8×10^{-9} C_4 C_6 J</td><td>1.0 $t^{0.75}$ $C_4 C_6$ J</td><td colspan="2">2×10^{-7} C_4 C_6 J</td><td colspan="4">7×10^{-4} $t^{0.75}$ C_4 C_6 J</td><td colspan="4" rowspan="2">α < 1.5 mrad: 3.9×10^{-4} C_4 C_7 W
α > 1.5 mrad: 7×10^{-4} C_4 C_6 C_7 $T_2^{-0.25}$ W
($t > T_2$)
($t \leq T_2$)
7×10^{-4} $t^{0.75}$ C_4 C_6 C_7 J</td></tr>
<tr><td>1 050 to 1 400</td><td>5.8×10^{-8} C_6 C_7 J</td><td>10.4 $t^{0.75}$ C_6 C_7 J</td><td colspan="3">2×10^{-6} C_6 C_7 J</td><td colspan="3">3.5×10^{-3} $t^{0.75}$ C_6 C_7 J</td></tr>
<tr><td>1 400 to 1 500</td><td colspan="2">8×10^5 W</td><td colspan="4">8×10^{-4} J</td><td>4.4×10^{-3} $t^{0.25}$ J</td><td>10^{-2} t J</td><td colspan="4" rowspan="4">1.0×10^{-2} W</td></tr>
<tr><td>1 500 to 1 800</td><td colspan="2">8×10^6 W</td><td colspan="5">8×10^{-3} J</td><td>1.8×10^{-2} $t^{0.75}$ J</td></tr>
<tr><td>1 800 to 2 600</td><td colspan="2">8×10^5 W</td><td colspan="4">8×10^{-4} J</td><td>4.4×10^{-3} $t^{0.25}$</td><td rowspan="2">10^{-2} t J</td></tr>
<tr><td>2 600 to 4 000</td><td colspan="2">8×10^4 W</td><td>8×10^{-5} J</td><td colspan="4">4.4×10^{-3} $t^{0.25}$ J</td></tr>
<tr><td>4 000 to 10^6</td><td colspan="2">10^{11} W.m^{-2}</td><td>100 J.m^{-2}</td><td colspan="5">5 600 $t^{0.25}$ J.m^{-2}</td><td colspan="4">1 000 W.m^{-2}</td></tr>
</table>

a For correction factors and units, see "Notes to table C1 to C4"

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

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

d In the wavelength range between 400 nm and 600 nm, dual limits apply and a product's emission must not exceed either limited applicable to the class assigned. If exposure times between 1 s and 10 s are used, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1.5 mrad and 82 mrad, the dual photochemical hazard limit of 3.9×10^{-3} C_3 J extended to 1 s.

Table C.2 – Accessible emission limits for Class 2 and Class 2M Laser products

Wavelength λ nm	Emission duration t s	Class 2 AEL
400 to 700	$t < 0.25$ $t \geq 0.25$	Same as Class 1 AEL $C_6 \times 10^{-3}$ W *
* For correction factor and units see "Notes to tables C1 to C4"		

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

<table>
<tr><th>Wavelength λ in mm \ Exposure time t in s</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to 10^{-7}</th><th>10^{-7} to 1.8×10^{-5}</th><th>1.8×10^{-5} to 5×10^{-5}</th><th>5×10^{-5} to 1×10^{-3}</th><th>1×10^{-3} to 0.35</th><th>0.35 to 10</th><th>10 to 10^{3}</th><th>10^{3} to 3×10^{4}</th></tr>
<tr><td>180 to 302.5</td><td colspan="2">Not appropriate</td><td colspan="8">Not appropriate</td></tr>
<tr><td>302.5 to 315</td><td colspan="2" rowspan="2">1.2×10^{5} W</td><td colspan="6">($t \le T_1$) $4 \times 10^{-6}\ C_1$ J
$7.0 \times 10^{-6}\ C_2$ J ($t > T_1$)</td><td colspan="2">$4.0 \times 10^{-6}\ C_2$ J</td></tr>
<tr><td>315 to 400</td><td colspan="6">$4.0 \times 10^{-6}\ C_1$ J</td><td>4.0×10^{-2} J</td><td>4.0×10^{-5} W</td></tr>
<tr><td>400 to 700</td><td>$2.9 \times 10^{-8}\ C_6$ J</td><td>$5.0\ t^{0.75}\ C_6$ J</td><td colspan="2">$1 \times 10^{-6}\ C_6$ J</td><td colspan="3">($t < 0.25$ s) $3.5 \times 10^{-3}\ t^{0.75}\ C_6$ J
$5.0 \times 10^{-3}\ C_6$ W ($t \ge 0.25$ s)</td><td>$5.0 \times 10^{-3}\ C_6$ W</td><td colspan="2">$5.0 \times 10^{-3}\ C_6$ W</td></tr>
<tr><td>700 to 1 050</td><td>$2.9 \times 10^{-8}\ C_4\ C_6$ J</td><td>$5.0\ t^{0.75}\ C_4\ C_6$ J</td><td colspan="2">$1 \times 10^{-6}\ C_4\ C_6$ J</td><td colspan="4">$3.5 \times 10^{-3}\ t^{0.75}\ C_4\ C_6$ J</td><td colspan="2" rowspan="2">$\alpha \le 1.5$ mrad: $2.0 \times 10^{-3}\ C_4\ C_7$ W
$\alpha > 1.5$ mrad: $3.5 \times 10^{-3}\ C_4\ C_6\ C_7\ T_2^{-0.25}$ W
($t > T_2$)
($t \le T_2$)
$3.5 \times 10^{-3}\ t^{0.75}\ C_4\ C_6\ C_7$ J</td></tr>
<tr><td>1 050 to 1 400</td><td>$2.9 \times 10^{-7}\ C_6\ C_7$ J</td><td>$52\ t^{0.75}\ C_6 C_7$ J</td><td colspan="3">$1 \times 10^{-5}\ C_6\ C_7$ J</td><td colspan="3">$1.8 \times 10^{-2}\ t^{0.75}\ C_6\ C_7$ J</td></tr>
<tr><td>1 400 to 1 500</td><td colspan="2">4×10^{6} W</td><td colspan="4">4×10^{-3} J</td><td>$2.2 \times 10^{-2}\ t^{0.25}$ J</td><td>$10^{-2}\ t$ J</td><td colspan="2" rowspan="4">5.0×10^{-2} W</td></tr>
<tr><td>1 500 to 1 800</td><td colspan="2">4×10^{7} W</td><td colspan="5">4×10^{-2} J</td><td>$9 \times 10^{-2}\ t^{0.75}$ J</td></tr>
<tr><td>1 800 to 2 600</td><td colspan="2">4×10^{6} W</td><td colspan="4">4×10^{-3} J</td><td>$4.4 \times 10^{-2}\ t^{0.25}$ J</td><td rowspan="2">$5 \times 10^{-2}\ t$ J</td></tr>
<tr><td>2 600 to 4 000</td><td colspan="2">4×10^{5} W</td><td>4×10^{-4} J</td><td colspan="4">$2.2 \times 10^{-2}\ t^{0.25}$ J</td></tr>
<tr><td>4 000 to 10^{6}</td><td colspan="2">5×10^{11} W.m^{-2}</td><td>500 J.m^{-2}</td><td colspan="5">$2.8 \times 10^{4}\ t^{0.25}$.m^{-2}</td><td colspan="2">5 000 W.m^{-2}</td></tr>
</table>

a For correction factors and units, see "Notes to table C1 to C4"

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

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

Wavelength λ nm \ Emission Duration t s	$<10^{-9}$	10^{-9} to 0.25	0.25 to 3×10^{4}
180 to 302.5	3.8×10^{5} W	3.8×10^{-4} J	1.5×10^{-3} W
302.5 to 315	1.25×10^{4} C_2 W	1.25×10^{-5} C_2 J	5×10^{-5} C_2 W
315 to 400	1.25×10^{8} W	0.125 J	0.5 W
400 to 700	3×10^{7} W	0.03 J for $t < 0.06$ s 0.5 W for $t \geq 0.06$ s	0.5 W
700 to 1 050	3×10^{7} C_4 W	0.03 C_4 J for $t < 0.06$ C_4 s 0.5 W for $t \geq 0.06$ C_4 s	0.5 W
1 050 to 1 400	1.5×10^{8} W	0.15 J	0.5 W
1 400 to 10^{6}	1.25×10^{8} W	0.125 J	0.5 W
For correction factors and units, see " Notes to tables C1 to C4"			

Notes to tables C1 to C4

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

NOTE 2 Correction factor C_1 to C_7 and breakpoints T_1 and T_2 used in tables C_1 to C_4 are defined in the following expressions and are illustrated in figures C.1 to C.8.

Parameter	Spectral region nm	Figures
$C_1 = 5.6 \times 10^{3}\ t^{0.25}$	302.5 to 400	1
$T_1 = 10^{0.8\,(\lambda-295)} \times 10^{-15}$ s	302.5 to 315	2
$C_2 = 10^{0.2(\lambda-295)}$	302.5 to 315	3
$T_2 = 10 \times 10^{[(\alpha-\alpha_{min})/98.5]}$ s [a]	400 to 1 400	4
$C_3 = 1.0$	400 to 450	5
$C_3 = 10^{0.02\,(\lambda-450)}$	450 to 600	5
$C_4 = 10^{0.002(\lambda-700)}$	700 to 1 050	6
$C_4 = 5$	1 050 to 1 400	6
$C_5 = N^{-1/4}$ [b]	400 to 10^{6}	7
$C_6 = 1$ for $\alpha \leq \alpha_{min}$	400 to 1 400	[c]
$C_6 = \alpha / \alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$	400 to 1 400	[c]
$C_6 = \alpha_{max} / \alpha_{min} = 66.7$ for $\alpha > \alpha_{max}$ [d]	400 to 1 400	[c]
$C_7 = 1$	700 to 1 150	8
$C_7 = 10^{0.018(\lambda-1150)}$	1 150 to 1 200	8
$C_7 = 8$	1 200 to 1 400	8

[a] $T_2 = 10$ s for $\alpha < 1.5$ mrad and $T_2 = 100$ s for $\alpha > 100$ mrad
[b] C_5 is only applicable to pulse durations shorter than 0.25 s
[c] C_6 is only applicable to pulsed lasers and to CW lasers where thermal injury dominates (see table C1)
[d] The limiting angle of acceptance γ shall be equal to α_{max}

$\alpha_{min} = 1.5$mrad
$\alpha_{max} = 100$mrad
N is the number of pulses contained within the applicable duration

NOTE 3 See table C.6 for limiting apertures.

NOTE 4 In the formulae in the tables C1 to C4 and in these notes, the wavelength has to be expressed in nanometers, the emission duration t has to be expressed in seconds and α has to be expressed in milliradians.

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

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

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

Table C.6 – Aperture diameter applicable to measuring laser irradiance and radiant exposure

Spectral region nm	Aperture diameter for Eye mm	Aperture diameter for Skin mm
180 to 400	1	3.5
≥ 400 to 1 400	7	3.5
≥ 1 400 to 10^5	1 for $t \leq 0.35$s 1.5 $t^{3/8}$ for $0.35\text{s} < t < 10$s 3.5 for $t \geq 10$s	3.5
≥ 10^5 to 10^6	11	11

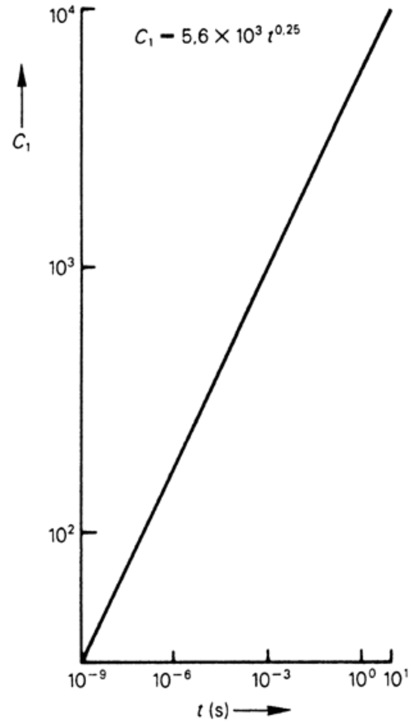


Figure C.1 – Correction factor C_1 for emission duration from 10^{-9} to 10 s

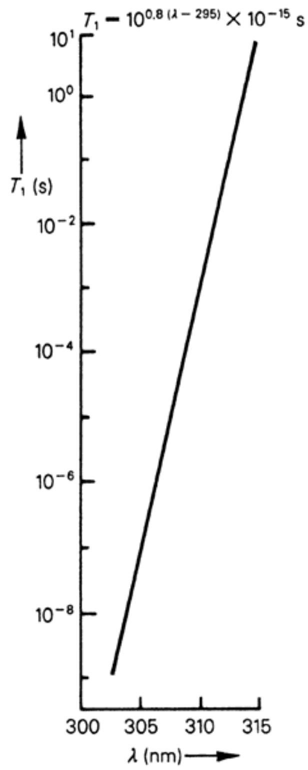


Figure C.2 – Breakpoint T_1 for λ = 302.5 nm to 315 nm

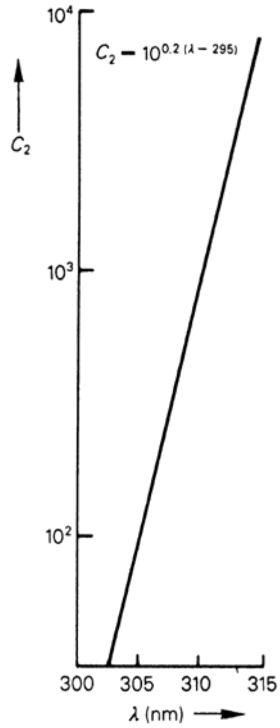


Figure C.3 – Correction factor C_2 for λ = 302.5 nm to 315 nm

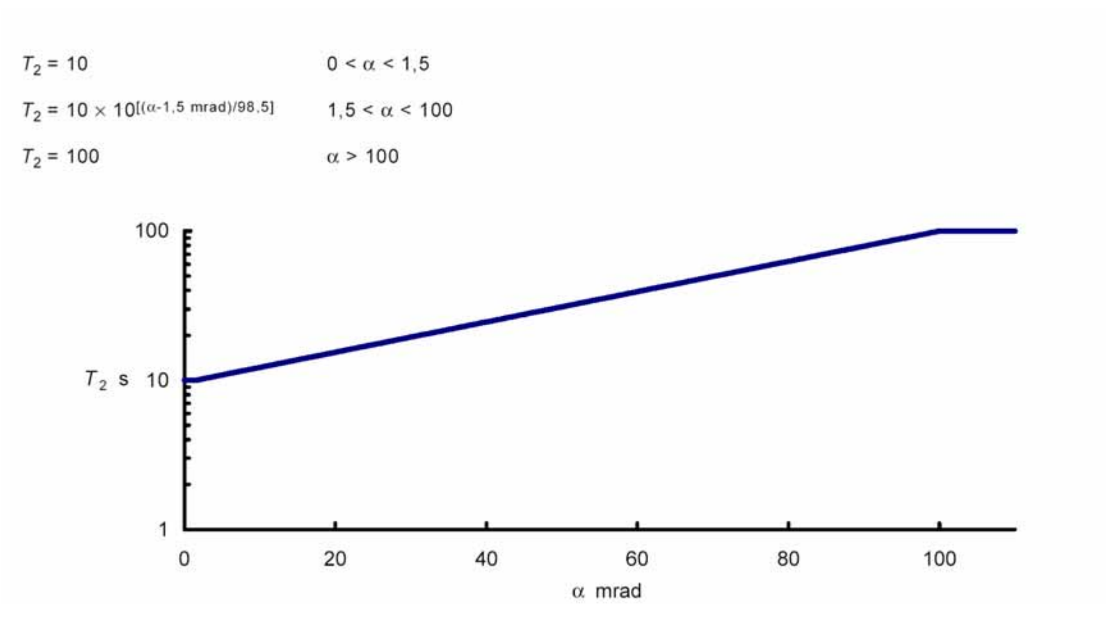


Figure C.4 – Breakpoint T_2 for source size α ranging from 0 mrad to more than 100 mrad

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

$C_3 = 10^{0.02(\lambda-450)}$ for $(450 < \lambda < 600)$

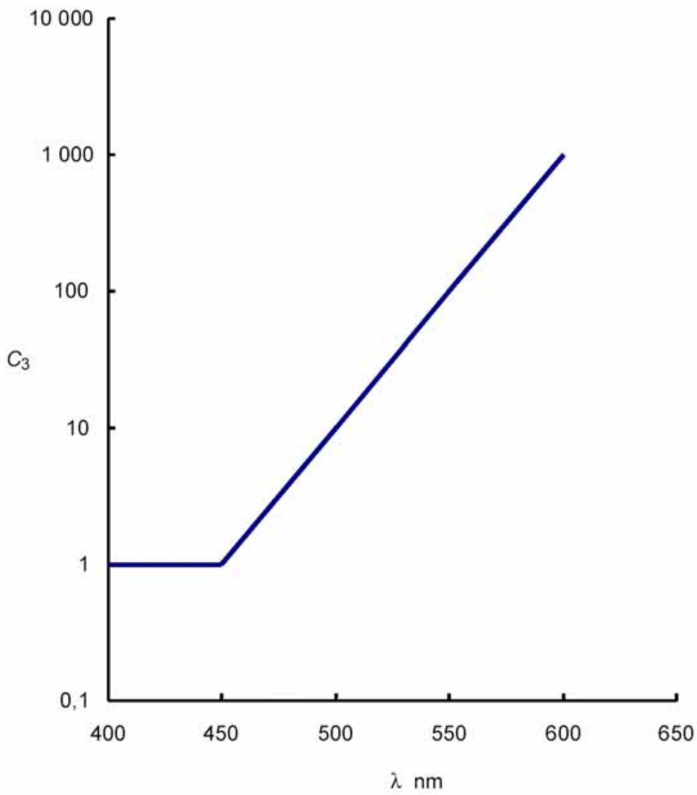


Figure C.5 – Correction factor C_3 for λ = 400 nm to 600 nm

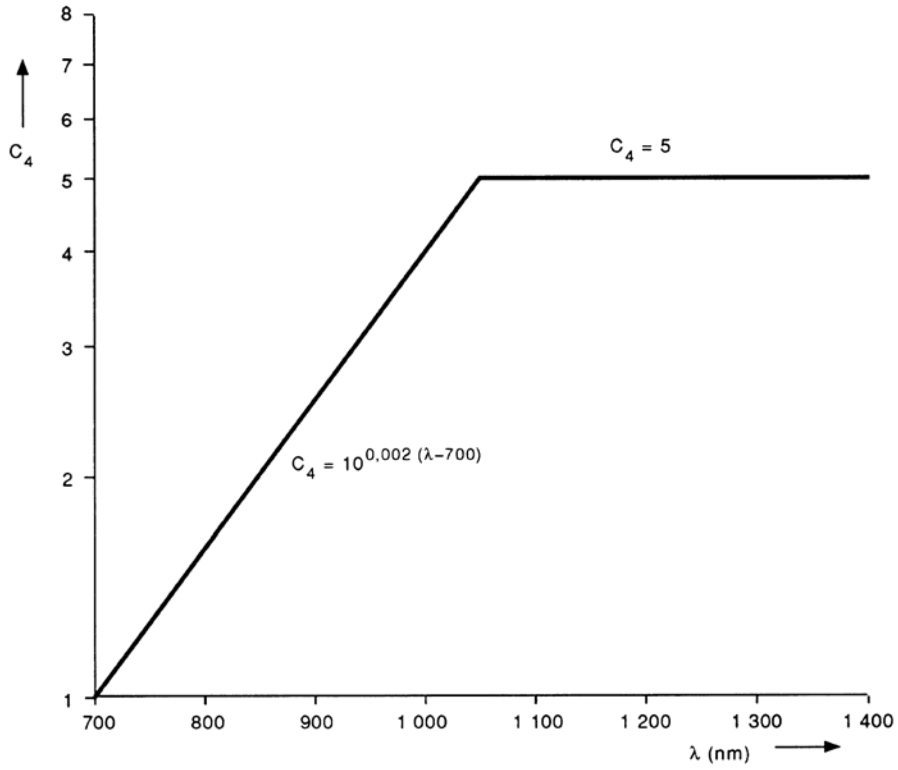


Figure C.6 – Correction factor C_4 for λ = 700 nm to 1 400 nm

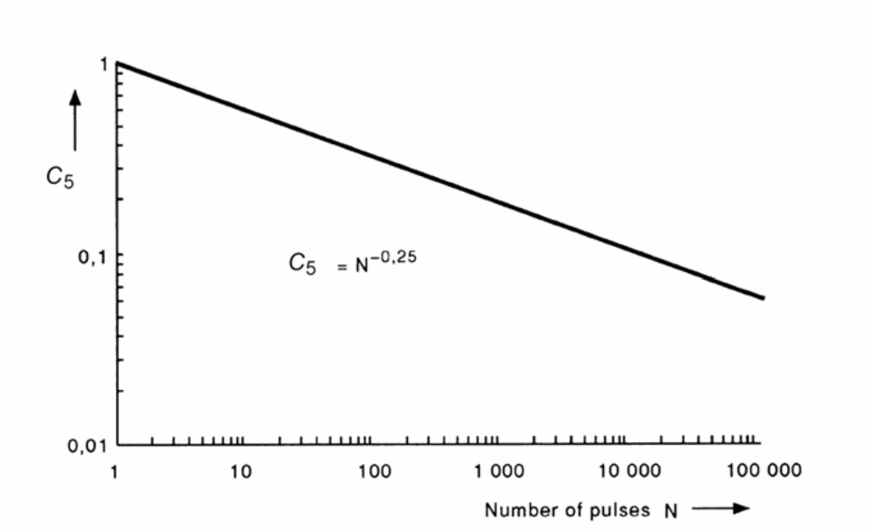


Figure C.7 – Correction factor C_5 shown for N (number of pulses) between 1 and 100 000

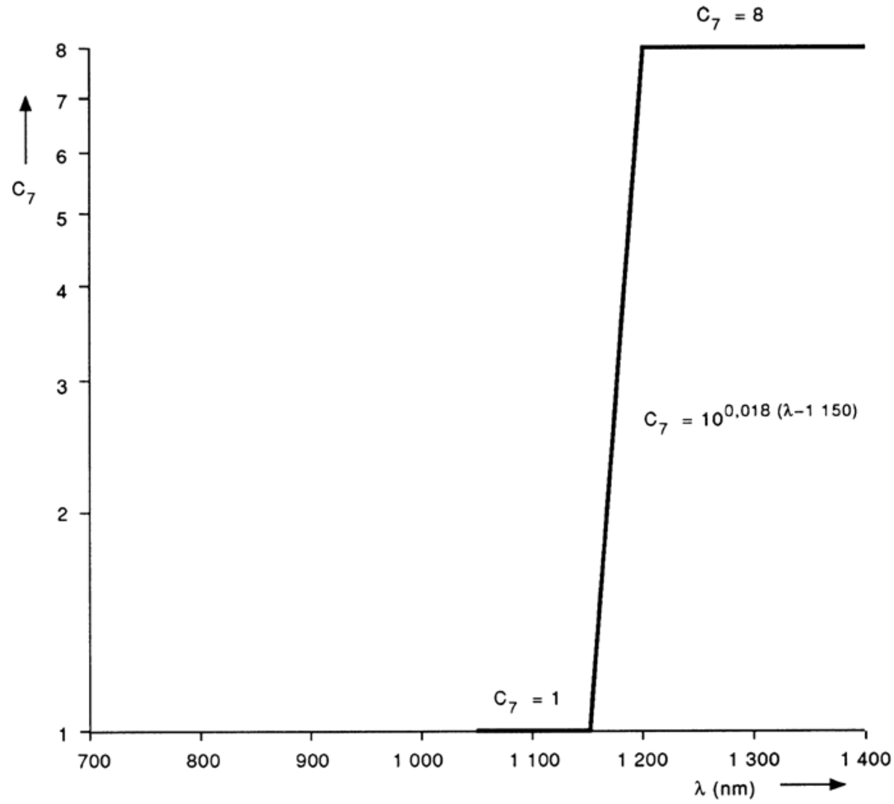


Figure C.8 – Correction factor C_7 for λ = 1 050 nm to 1 400 nm

Abstracted from IEC 60825-1:2001

TEST MEASUREMENTS OF LASER RADIATION LEVELS FOR CLASSIFICATION PURPOSES

General

D.1 Tests shall account for all errors and statistical uncertainties in the measurement process and increases in emission and degradation in radiation safety with age.

D.2 Tests for each of the applicable requirements shall be made during operation, maintenance or service, as appropriate.

Note 1. Any test procedure showing compliance with the requirements of Clause 8 of IEC 60825-1:2001 (i.e. D.3 and D.4 of Annex D) is acceptable.

Note 2. Specific use requirements may impose additional tests.

Measurements of laser radiation levels for classification purposes

D.3 Measurements shall be made under the following conditions:

a) under those conditions and procedures that maximize the accessible emission levels, including start-up, stabilized emission and shut-down of the laser product;

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

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

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

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

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

g) Class 1 and Class 1M

In the wavelength range of 302.5 nm to 4000 nm, if the level of radiation, as determined according to table D.1, for condition 1 and condition 2 is less than, or equal to, the AEL of Class 1, the laser product is assigned to Class 1.

If the level of radiation, as determined according to table D.1, is larger than the AEL of Class 1 for condition 1 or condition 2 and less than the AEL of

Class 3B, but with an aperture stop of diameter and at a distance from the apparent source as specified in table D.1 for irradiant exposure measurements is less than, or equal to, the AEL of Class 1, the laser product is assigned to Class 1M.

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

h) Class 2 and Class 2M

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

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

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

D.4 Measurement geometry

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

For power and energy measurement of scanned laser radiation, the measurement apertures and distances as specified in table D.1 for irradiance or radiant exposure shall be used.

(a) Aperture diameters

The aperture diameters used for measurements of radiation for classification purposes shall be as shown in Table D.1.

NOTE Irradiance and radiant exposure values should not be averaged over apertures smaller than the limiting apertures given in table D.1 for irradiance and radiant exposure.

(b) Measurement distance

For condition 1, the measurement distance specified in Table D.1 refers to the distance between the closest point of human access and the aperture stop; for condition 2 and irradiance or radiant exposure measurements the measurement distance refers to the distance between the apparent source and the aperture stop. Outside the wavelength range of 302.5 nm and 4000 nm, the differentiation into condition 1 and condition 2 does not apply and the distance specified in Table D.1 refers to the distance between the closest point of human access and the aperture stop.

For the purpose of IEC60825-1:2001 standard, the location of the beam waist shall be considered as the location of the apparent source in determining the measurement distance as given in Table D.1; however, the location and size of the beam waist should not be used to geometrically determine the angular subtense of the apparent source. If a value of angular subtense greater than α_{min} is to be used for classification, the dimensions of the apparent source shall be determined. In the case of scanning beams, the appropriate measurement location is the location where the combination of angular subtense and pulse duration results in the most restrictive accessible emission limit (AEL).

NOTE For the measurement of power and energy for condition 2 and the measurement of irradiance or radiant exposure in the wavelength range of 302.5 nm to 4000 nm. In cases where the apparent source is not accessible by virtue of engineering design (for example, recessed), the measurement distance should be at the closest point of human access but not less than the specified distance.

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

$d = (7mm)\sqrt{\frac{\alpha_{\max}}{\alpha + 0.46mrad}}$ If $\alpha < \alpha_{min}$, d = 50 mm. If $\alpha \geq \alpha_{max}$, d = 7 mm.

NOTE The measurement apertures and distances in table D.1 describe the geometry of the measurement conditions required to determine the radiation level to be used for classification. In some cases, it may be appropriate, because of instrument or space limitations, to use an equivalent arrangement of apertures and distances. For example, as an alternative to a 7 mm diameter aperture stop placed at a distance of 14 mm from the apparent source, an aperture stop with a diameter of 50 mm can be placed at a distance of 100 m from the apparent source.

Table D.1 – Diameters of the measurement apertures and measurement distances

Wavelength nm	For values expressed in power W or energy J				For irradiance W/m^{2} [b] or radiant exposure J/m^{2} [b]	
	Condition 1		Condition 2			
For Class 1 see also D.3(g) For Class 2 see also D.3(h)	Aperture stop mm	Distance mm	Aperture stop mm	Distance mm	Limiting aperture mm	Distance mm
< 302.5 nm	-	-	7	14	1	0
≥ 302.5 nm to 400 nm	25	2000	7	14	1	100
≥ 400 nm to 1400 nm	50	2000	7[a]	r[a]	7	100
≥ 1400 nm to 4000 nm	25	2000	7	14	1 for $t \le 0.35$ s 1.5 $t^{3/8}$ for $0.35 \text{ s} < t < 10$ s 3.5 for $t \ge 10$ s (t in s)	100
≥ 400 nm to 10^5 nm	-	-	7	14	1 for $t \le 0.35$ s 1.5 $t^{3/8}$ for $0.35 \text{ s} < t < 10$ s 3.5 for $t \ge 10$ s (t in s)	0
≥ 10^5 nm to 10^6 nm	-	-	7	14	11	0

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

r = 14 mm for $\alpha \le 1.5$ mrad

r = 100 mm (α/11 mrad) for 1.5 mrad < $\alpha \le 11$ mrad

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

(for the test for Class 1M and 2M, refer to D.3(g) and D.3(h))

For the photochemical limits and t > 100 s, r is given by (for the definition of γ_p refer to D.4(c))

r = 14 mm for $\alpha \le 1.5$ mrad

$$r = \left[14 + 86\frac{\alpha - 1.5mrad}{\gamma_p - 1.5mrad}\right]mm$$ for 1.5 mrad < $\alpha \le \gamma_p$

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

(for the test for Class 1M and 2M, refer to D.3(g) and D.3(h))

For thermal limits, r is given by

$$r = \left[(100mm)\sqrt{\frac{\alpha + 0.46mrad}{\alpha_{\max}}} \right]$$ if $\alpha < \alpha_{min}$, r = 14 mm. If $\alpha \geq \alpha_{max}$, r = 100 mm

(for the test for Class 1M and 2M, refer to D.3(g) and D.3(h))

[b] In the wavelength range of 400 nm to 4000 nm, these values are also applicable for the measurement of power or energy for Class 1M and Class 2M (D.3(g) and D.3(h))

(c) Angle of acceptance

(i) Photochemical retinal limits

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

for 10 s < t ≤ 100 s: γ_p = 11 mrad

for 100 s < t ≤ 10^4 s: $\gamma_p = 1.1t^{0.5}$ mrad

for 10^4 s < t ≤ 3 X 10^4 s: γ_p = 110 mrad

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

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

(ii) All other limits

For measurement of radiation to be compared to limits other than the photochemical limits, the angle of acceptance shall fully encompass the source under consideration (i.e. the angle of acceptance shall be at least as large as the angular subtense of the source α). However, if $\alpha > \alpha_{max}$, in the wavelength range of 302.5 nm to 4 000 nm, the limiting angle of acceptance is α_{max} (100 mrad). Within the wavelength range of 400 nm to 1 400 nm, for the evaluation of an apparent source which consists of multiple points, the angle of acceptance has to be varied in the range of $\alpha_{min} \leq \gamma \leq \alpha_{max}$ (see E.13 of Annex E).

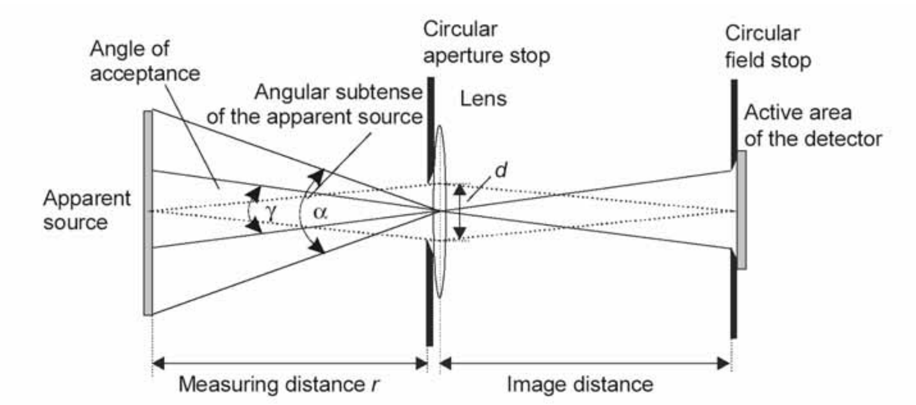


Figure D.1(a)

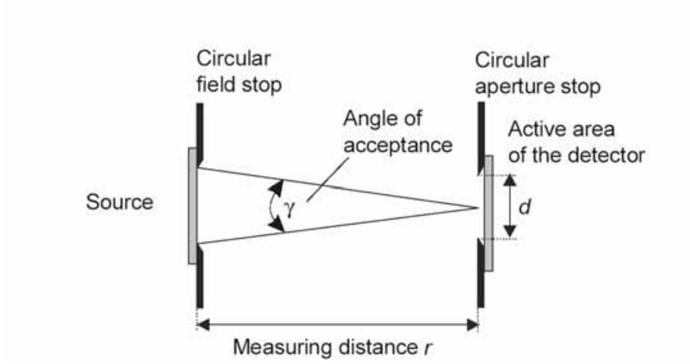


Figure D.1(b)

Figure D.1 – Measurement set-up to obtain a well-defined angle of acceptance – D.1(a): by imaging the apparent source onto the plane of the field stop – D.1(b): by placing a circular aperture or a mask (serving as field stop) close to the source

The angle of acceptance is determined by the ratio of the diameter of the field stop and the lens-field stop distance (image distance) (Figure D.1(a)), or by the ratio of the diameter of the field stop and the source-detector distance (Figure D.1(b)). Transmission and reflection losses due to the lens have to be taken into account. The measuring distance r as specified in Table D.1 is taken from the aperture stop.

Abstracted from IEC 60825-1:2001

LASER PRODUCT CLASSIFICATION

1. DEFINITION OF LASER PRODUCT CLASSES

E.1 Laser products shall be grouped into classes as specified in E.1 (a) to E.1 (g) for each of which accessible emission limits (AELs) are specified.

(a) Class 1 laser products. Class 1 laser products shall be those that are safe under reasonably foreseeable conditions of operation, including the use of optical instruments for intrabeam viewing. Class 1 laser products do not permit human access to laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission durations (see Table C.1 of Annex C)

(b) Class 1M laser products. Class 1M laser products shall be those that do 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 according to Annex D, however, evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 1 laser products. (see Table C.1 of Annex C) Class 1 M laser products are safe under reasonably foreseeable conditions of operation, but may be hazardous if the user employs optics within the beam.

(c) Class 2 laser products. Class 2 laser products shall be those that emit visible radiation in the wavelength range from 400 nm to 700 nm where eye protection is normally afforded by aversion responses, including the blink reflex. This reaction may be expected to provide adequate protection under reasonably foreseeable conditions of operation including the use of optical instruments for intrabeam viewing. Class 2 laser products do not permit human access to laser radiation in excess of the accessible emission limits of Class 2 for applicable wavelengths and emission durations. (Table C.2 of Annex 2)

(d) Class 2M laser products. Class 2M laser products shall be those that emit in the wavelength range from 400 nm to 700 nm which do 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 according to Annex D, however, evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for Class 2 laser products. (see Table C.2 of Annex C) Class 2M laser products emit visible radiation where eye protection is normally afforded by aversion responses including the blink reflex. However, viewing of the output may be more hazardous if the user employs optics within the beam.

(e) Class 3R laser products. Class 3R laser products shall be those that emit in the wavelength range from 302.5 nm to 10^6 nm where direct intrabeam viewing is potentially hazardous but the risk is lower than for Class 3B lasers, and fewer manufacturing requirements and control measures for the user apply than for Class 3B lasers. The accessible emission limit is within five times the AEL of Class 2 in the wavelength range from 400 nm to 700 nm and within five times the AEL of Class 1 for other wavelengths. (see Table C.3 of Annex C)

(f) Class 3B laser products. Class 3B laser products shall be those that may emit visible and/or invisible radiation not exceeding the AELs specified in Table C.4 of Annex C. Emission shall not exceed 0.5 W for CW lasers (emission duration longer than 0.25 s).

Note. Direct intra-beam viewing of these devices may be hazardous but under certain conditions they may be safety viewed via a diffuse reflector. These conditions are:

(i) a minimum viewing distance of 13 cm between screen and cornea; and

(ii) a maximum viewing time of 10 s.

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

(g) Class 4 laser products. Class 4 laser products shall be high output devices, with outputs exceeding the AELs specified in Table C.4 of Annex C for Class 3B , that are capable of producing hazardous diffuse reflections.

Note. They may cause skin injuries and could also constitute a fire hazard. Their use requires extreme caution.

2. CLASSIFICATION PROCEDURE

Responsibility to Classify

E.2 It is the responsibility of the manufacturer or his agent to provide correct classification of a laser product.

E.3 Any previously classified laser product that is subsequently modified, so as to affect any aspect of the product's performance or intended function within the scope of IEC60825-1:2001 standard, shall be examined and if necessary re-classified. The person or organisation performing any such modification is responsible for ensuring the re-classification and re-labelling of the laser product and for meeting the provision of paragraphs E.1 to E.13.

Rules for the Assignment of a Laser Product to a Particular Class

E.4 General. The product shall be classified on the basis of that combination of output power(s) and wavelength(s) of the accessible laser radiation over the full range of operational capability at any time after manufacture that results in its allocation to the highest appropriate class.

Note. The AELs for Class 1 and 1M, Class 2 and 2M, Class 3R and Class 3B (listed in order of increasing hazard) are specified in Table C.1 to C.4 of Annex C.

E.5 Time bases for classification. The following time bases are used for classification:

(a) 0.25 s for Class 2, Class 2M and Class 3R laser radiation in the wavelength range from 400 nm to 700 nm.

(b) 100 s for laser radiation of all wavelengths greater than 400 nm except for the cases listed in (a) and (c).

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

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

E.6 Radiation of a single wavelength. A single wavelength laser product, with a spectral range of the emission line narrow enough so that the AELs do not change, shall be assigned to a class when the accessible laser radiation, measured under the conditions appropriate to that class, exceeds the AEL of all lower classes but does not exceed that of the class assigned.

E.7 Radiation of multiple wavelengths

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

(b) A laser product emitting two or more wavelengths in spectral regions not shown as additive in Table C.5 of Annex C shall be assigned to a class when the accessible laser radiation, measured under the conditions appropriate to that class, exceeds the AELs of all lower classes for at least one wavelength but does not exceed the AEL for the class assigned for any wavelength.

E.8 <u>Radiation from extended sources</u>

The ocular hazard from laser sources in the wavelength range from 400 nm to 1400 nm is dependent upon the angular subtense of the source. A source is considered an extended source when the angular subtense of the source is greater than α_{min}, where α_{min} = 1.5 mrad. For retinal thermal hazard evaluation (400 nm to 1400 nm), the AELs for extended sources vary directly with the angular subtense of the source. For the retinal photochemical hazard evaluation (400 nm to 600 nm), for exposures greater than 1 s, the AELs do not vary directly with the angular subtense of the source, but, depending on the exposure duration(D.4 (c) (i) of Annex D), a limiting angle of acceptance γ_p of 11 mrad or more is used for measurement, and the relation of the limiting acceptance angle γ_p to the angular subtense α of the source can influence the measured value.

E.9 For sources subtending an angle less than or equal to α_{min}, the AEL and MPE are independent of the angular subtense of the source α.

E.10 For an extended source, the power or energy measured must be below the permitted power or energy for the AEL specified for the class as a function of the angular subtense of the source α.

E.11 For classifying laser products where condition 1 applies (see table D1 of Annex D), the angular subtense α of the apparent source shall be determined at the location of the 50 mm measurement aperture. The 7X magnification of the angular subtense α of the apparent source may be applied to determine C_6, i.e. $C_6 = 7 \text{ X } \alpha / \alpha_{min}$, provided that it can be demonstrated that the smallest possible retinal spot diameter will not be less than C_6 X 25 um when the radiation is viewed through an optical instrument of magnification 7. The expression (7 X α) shall be limited to α_{max} prior to the calculation of C_6.

NOTE For the case that $\alpha < 1.5$ mrad but 7 X $\alpha > 1.5$ mrad, the limits for $\alpha > 1.5$ mrad of table 1 and 3 apply, provided that the 7X magnification of the retinal spot diameter can be demonstrated.

E.12 For classify laser products where condition 2 applies (see table D1 of Annex D), the angular subtense α of the apparent source shall be determined at the nearest point of human access to the apparent source, but not less than 100 mm.

E.13 <u>Non-circular and multiple sources</u>

For laser radiation where the apparent source consists of multiple points or is a linear source with an angular subtense greater than α_{min} and within the wavelength range from 400 nm to 1400 nm, measurements or evaluations shall be made for every single point, or assembly of points, necessary to assure that the source does not exceed the AEL for each possible angle α subtended by each partial area, where $\alpha_{min} \leq \alpha \leq \alpha_{max}$. For the retinal photochemical hazard limits (400 nm to 600 nm), the limiting angle of acceptance γ_p to be used to evaluate extended sources is specified in D.4 (c) (i) of Annex D.

E.14 For the determination of the AEL retinal thermal hazard limits (400 nm to 1400 nm), the value of the angular subtense of a rectangular or linear source is determined by the arithmetic mean of the two angular dimensions of the source. Any angular dimension that is greater than α_{max} or less than α_{min} shall be limited to α_{max} or α_{min} respectively, prior to calculating the mean. The photochemical limits (400 nm to 600 nm) do not depend on the angular subtense of the source, and the source is measured with the angle of acceptance specified in D.4 (c) of Annex D.

Repetitively-pulsed or Modulated Lasers

E.15 Since there is only limited information on multiple pulse exposure criteria, caution is necessary in the evaluation of exposure to repetitively-pulsed radiation. The methods given in paragraphs E.16 to E.20 shall be used to determine the AEL to be supplied to repetitive exposures.

E.16 The AEL for wavelengths from 400nm to 10^6 is determined by using the most restrictive of requirements (a), (b) and (c), as appropriate. For other wavelengths, the AEL is determined by using the most restrictive of requirements (a) and (b). Requirement (c) applies only to the thermal limits, not to the photochemical limits.

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

(b) The average power for a pulse train of emission duration T shall not exceed the power corresponding to the AEL given in Tables C.1 to C.4 of Annex C for a single pulse of the emission duration T.

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

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

where

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

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

$C_5 = N^{-0.25}$;

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

Wavelength	Duration to determine N
400 nm to 1400 nm	T_2 (see note 2 of the notes to tables C1 to C4) or the applicable time basis, whichever is shorter
> 1400 nm	10 s

C_5 is only applicable to individual pulse durations shorter than 0.25 s.

E.17 In some cases, the calculated value may fall below the AEL that would apply for continuous operation at the same peak power using the same time base. Under these circumstances, the AEL for continuous operation may be used.

E.18 If multiple pulses appear within the period of T_i (see table E1 of Annex E), they are counted as a single pulse to determine N and the energies of the individual pulses are added to be compared to the AEL of T_i, provided that all individual pulse durations are greater than 10^{-9} s.

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

Table E.1 – Times T_i below which pulse groups are summed up

Wavelength	T_i
400 nm ≤ λ < 1050 nm	18 X 10^{-6} s
1050 nm ≤ λ < 1400 nm	50 X 10^{-6} s
1400 nm ≤ λ < 1500 nm	10^{-3} s
1500 nm ≤ λ < 1800 nm	10 s
1800 nm ≤ λ < 2600 nm	10^{-3} s
2600 nm ≤ λ < 10^6 nm	10^{-7} s

E.19 In cases of varying pulse widths or pulse intervals, the total-on-time-pulse (TOTP) method may be used in place of requirement iii). In this case, the AEL is determined by the duration of the TOTP, which is the sum of all pulse durations within the emission duration or T_2, whichever is smaller. Pulses with durations less than T_i, are assigned pulse durations of T_i. If two or more pulses occur within a duration of T_i, these pulse groups are assigned pulse durations of T_i. For comparison with the AEL for the corresponding duration, all individual pulse energies are added.

E.20 This method is equivalent to requirement E.16 (c) of Annex E when the average energy of pulses is compared to the AEL of a single pulse multiplied with C_5.

Annex F

LASER EQUIPMENT RECORD

Name of Company / Education Institution : ______________________________

Contact Person : ______________________________

Telephone no. : ______________________________

Laser Equipment Possessed / Supplied:

(Manufacturer /Model)

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________

PLEASE FILL IN ONE DETAILED INFORMATION SHEET AND ATTACH A CATALOGUE FOR EACH OF THE ABOVE MODELS

DETAILED INFORMATION

Manufacturer : ______________________________

Model : ______________ Country of Origin : __________

Supplier : ____________________ Price : __________

Class of Laser : ______________ Lasing Media : __________

Purpose : Educational / Demonstration /
Industrial Laboratory / Entertainment /
Surveying / Others*
(If others, please specify)

____

Date of Purchase / Installation : ____________________

Warranty Period : ________years

Maintenance Arrangement Upon Expiry of Warranty : __________

Name of Designated Laser Safety Officer : ______________

Operating Training : Yes / No* Duration of Training : __________

Key-operated Switch : Yes / No* Warning Label : Yes / No*

Illuminated ON/OFF Switch or Operation Indication Light : Yes / No*

Output beam diameter : __________ Beam Divergency : __________

Specific Parameters :

⑥ Continuous Wave Mode		⑥ Pulse Mode			
Wavelength	Maximum Power	Wavelength	Energy Per Pulse	Pulse Duration	Pulse Repetition Frequency

Any physical Accidents and Injuries in the Course of Operation or Servicing?
Yes / No *

If Yes, brief Description of the accident / injury:

____

____

* Please delete as appropriate

Annex G
Abstracted from IEC 60825-1:2001

Information Supplied to Purchasers

Information for the User

G.1 Manufacturers of laser products shall provide with each laser product the following information as listed in (a) to (j).

Note. If a manual is provided this information should be incorporated in it.

(a) Adequate instructions for proper installation, maintenance and safe use, including clear warnings concerning precautions to avoid possible exposure to laser radiation in excess of the accessible emission limits (AELs) specified in Tables C.1 to C.4 of Annex C.

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

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

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

(e) Legible reproductions (in the appropriate colours or black and white) of all labels and hazard warnings to be affixed to the laser product or provided with it in accordance with Annex I.

(f) An indication of the position of each label affixed to the laser product, or, if the labels are provided with the laser product, both a statement that such labels could not be affixed to the product but were supplied with it and a statement of the form and manner in which they were supplied.

(g) A clear indication of all locations of laser apertures.

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

(i) For laser products that do not incorporate the laser energy source necessary for the laser emission, a statement of the compatibility requirements for a laser energy source to ensure safety.

(j) Any other information relevant to the safe use of the laser product.

Purchasing and Servicing Information

G.2 Manufacturers of laser products shall provide or cause to be provided:

(a) in all catalogues, specification sheets and descriptive brochures pertaining to each laser product, legible reproductions (in the appropriate colours or black and white) of the appropriate classification labels (see Figures I.1 and I.2 of Annex I) that are normally affixed thereto in accordance with Annex I; and

(b) to servicing dealers and distributors (and to others upon request), in respect of each laser product model;

(1) adequate instructions both for adjustments and for servicing procedures, to include clear warnings and precautions to be taken to avoid possible exposure to radiation;

(2) a schedule of maintenance necessary to keep the product in safe working order;

(3) a statement of those controls and procedures that could be used (other than by the manufacturer or his agents) to increase the accessible levels of radiation; and

(4) a clear description of the location of displaceable portions of the protective housing that could allow exposure to laser radiation in excess of the AELs appropriate to the laser product concerned. Such instructions shall include

protective procedures for servicing personnel and legible reproductions (in the appropriate colours or black and white) of the labels and hazard warnings that are affixed to the product(s) concerned.

Annex H

Abstracted from IEC 60825-1:2001

CONTROL MEASURES FOR THE LASERS

Requirements Subclause	Classification						
	Class 1	Class 1M	Class 2	Class 2M	Class 3R	Class 3B	Class 4
Laser safety officer	Not required but recommended for applications that involve direct viewing of the laser beam				Not required for visible emission Required for non-visible emission	Required	
Remote interlock	Not required					Connect to room or door circuits	
Key control	Not required					Remove key when not in use	
Beam attenuator	Not required					When in use prevents inadvertent exposure	
Emission indictor device	Not required				Indicates laser is energized for non-visible wavelengths	Indicates laser is energized	
Warning signs	Not required					Follow precautions on warning signs	
Beam path	Not required	Class 1M [a] as for Class 3B	Not required	Class 2M [b] as for Class 3B	Terminate beam at end of useful length		
Specular reflection	No requirements	Class 1M [a] as for Class 3B	Not requirements	Class 2M [b] as for Class 3B	Prevent unintentional reflections		
Eye protection	No requirements					Required if engineering and administrative procedures and practicable and MPE exceeded	
Protective clothing	No requirements					Sometimes required	Specific requirements
Training	No requirements	Class 1M [a] as for Class 3B	Not requirements	Class 2M [b] as for Class 3B	Required for all operator and maintenance personnel		
[a] Class 1M laser products that failed condition 1 of table D.1. Not required for Class 1M laser products that failed condition 2 of table D.1. [b] Class 2M laser products that failed condition 1 of table D.1. Not required for Class 2M laser products that failed condition 2 of table D.1.							
NOTE This table is intended to provide a convenient summary of precautions. See text of this standard for complete precautions.							

Annex I

Abstracted from IEC 60825-1:2001

LABELLING

I.1 General

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

I.2 Class 1

Each Class 1 laser product shall have affixed an explanatory label (Figure I.2), bearing the words:

Class 1 LASER PRODUCT

Suggested Chinese version:

1 類激光產品

I.3 Class 1M

Each Class 1M laser product shall have affixed an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS

CLASS 1M LASER PRODUCT

Suggested Chinese version:

激光輻射

切勿透過視光儀器直視

1M 類激光產品

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

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

I.4 Class 2

Each Class 2 laser product shall have affixed a warning label (Figure I.1) and an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

DO NOT STARE INTO BEAM

CLASS 2 LASER PRODUCT

Suggested Chinese version:

激光輻射

勿直視激光束

2 類激光產品

I.5 Class 2M

Each Class 2M laser product shall have affixed a warning label

(Figure I.1) and an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

DO NOT STARE INTO BEAM OR VIEW

DIRECTLY WITH OPTICAL INSTRUMENTS

CLASS 2M LASER PRODUCT

Suggested Chinese version:

激光輻射

勿直視激光束或透過視光儀器直視激光束

2M 類激光產品

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

I.6 Class 3R

Each Class 3R laser product in the wavelength range from 400 nm to 1400 nm shall have affixed a warning label (Figure I.1) and an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

AVOID DIRECT EYE EXPOSURE

CLASS 3R LASER PRODUCT

Suggested Chinese version:

激光輻射

勿直視激光束

3R 類激光產品

For other wavelengths, each Class 3R laser product shall have affixed a warning label (Figure I.1) and an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

AVOID EXPOSURE TO BEAM

CLASS 3R LASER PRODUCT

Suggested Chinese version:

激光輻射

避免激光照射

3R 類激光產品

I.7 Class 3B

Each Class 3B laser product shall have affixed a warning label (Figure I.1) and an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

AVOID EXPOSURE TO BEAM

CLASS 3B LASER PRODUCT

Suggested Chinese version:

激光輻射

避免激光照射

3B 類激光產品

I.8 Class 4

Each Class 4 laser product shall have affixed a warning label (Figure I.1) and an explanatory label (Figure I.2) bearing the words:

LASER RADIATION

AVOID EYE OR SKIN EXPOSURE TO

DIRECT OR SCATTERED RADIATION

CLASS 4 LASER PRODUCT

Suggested Chinese version:

激光輻射

避免眼或皮膚受到直射或散射輻射

4 類激光產品

I.9 Aperture label

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

LASER APERTURE

or

AVOID EXPOSURE – LASER RADIATION IS

EMITTED FROM THIS APERTURE

Suggested Chinese version:

激光窗孔

or

避免受到照射－此窗孔發射激光幅射

I.10 Radiation output and standards information

Each laser product (except those Class 1) shall be described on the explanatory label (Figure I.2) by statements of the maximum output of laser radiation, the pulse duration (if appropriate) and the emitted wavelength(s). The name and publication date of the standard to which the product was classified shall be included on the explanatory label or elsewhere in close proximity on the product. For Class 1 and Class 1M, instead of the labels on the product, the information may be contained in the information for the user.

I.11 Labels for access panels

I.11.1 Labels for panels

Each connection, each panel of a protective housing, and each access panel of a protective enclosure which when removed or displaced permits human access to laser radiation in excess of the AEL for Class 1 shall have affixed a label bearing the words (for the case of an embedded Class 1M laser, the statement instead may be included in the information for the user):

CAUTION – LASER RADIATION WHEN OPEN

Suggested Chinese version:

注意－打開時有激光輻射

In addition, this label shall bear the words:

(a) CAUTION – CLASS 1M LASER RADIATION WHEN OPEN

DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS

Suggested Chinese version:

注意－打開時有 1M 類激光輻射

切勿透過視光儀器直視激光束

if the accessible radiation does not exceed the AEL for Class 1M where the level of radiation is measured.

(b) CAUTION – CLASS 2 LASER RADIATION WHEN OPEN

DO NOT STARE INTO THE BEAM

Suggested Chinese version:

注意－打開時有 2 類激光輻射

勿直視激光束

if the accessible radiation does not exceed the AEL for Class 2 where the level of radiation is measured.

(c) CAUTION – CLASS 2M LASER RADIATION WHEN OPEN

DO NOT STARE INTO THE BEAM OR VIEW

DIRECTLY WITH OPTICAL INSTRUMENTS

Suggested Chinese version:

注意－打開時有 2M 類激光輻射

勿直視激光束或

透過視光儀器直視光束

if the accessible radiation does not exceed the AEL for Class 2M where the level of radiation is measured.

(d) CAUTION – CLASS 3R LASER RADIATION WHEN OPEN

AVOID DIRECT EYE EXPOSURE

Suggested Chinese version:

注意－打開時有 3R 類激光輻射

勿直視激光束

if the accessible radiation is in the wavelength range from 400 nm to 1400 nm and does not exceed the AEL for Class 3R;

(e) CAUTION – CLASS 3R LASER RADIATION WHEN OPEN

AVOID EXPOSURE TO THE BEAM

Suggested Chinese version:

注意－打開時有 3R 類激光輻射

避免激光照射

if the accessible radiation is outside the wavelength range from 400 nm to 1400 nm and does not exceed the AEL for Class 3R;

(f) CAUTION – CLASS 3B LASER RADIATION WHEN OPEN

AVOID EXPOSURE TO THE BEAM

Suggested Chinese version:

注意－打開時有 3B 類激光輻射

避免激光照射

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

(g) CAUTION – CLASS 4 LASER RADIATION WHEN OPEN

AVOID EYE OR SKIN EXPOSURE TO

DIRECT OR SCATTERED RADIATION

Suggested Chinese version:

注意－打開時有 4 類激光輻射

避免眼或皮膚受到直射或散射輻射

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

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

I.11.2 Labels for safety interlocked panels

Appropriate labels shall be clearly associated with each safety interlock which may be readily overridden and which would then permit human access to laser radiation in excess of the AEL of Class 1. Such labels shall be visible prior to and during interlock override and be in close proximity to the opening created by the removal of the protective housing. This label shall bear the words specified in items a) to g) of I.11.1, with the introduction of an additional line, positioned after the first line, with the following words:

AND INTERLOCKS DEFEATED

Suggested Chinese version:

聯銷消除

I.12 Warning for invisible laser radiation

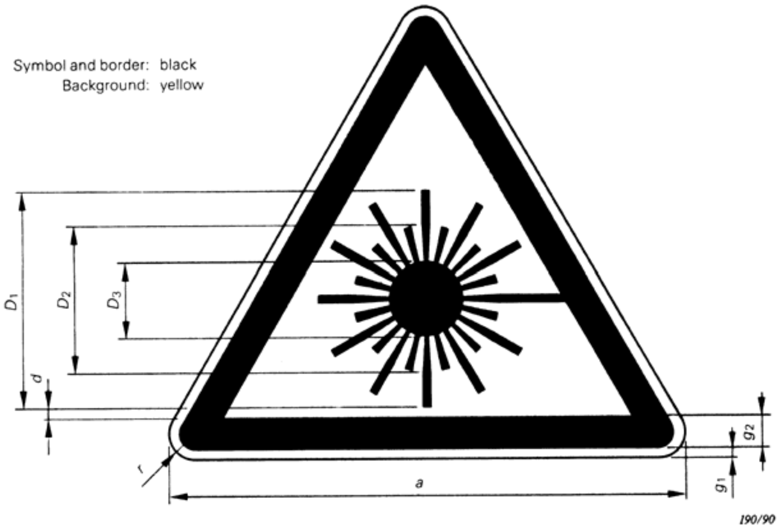
In many cases, the wording prescribed for explanatory labels includes the phrase "laser radiation". If the output of the laser is outside the wavelength range 400 nm to 700 nm, this shall be modified to read "Invisible laser radiation", or if the output is at wavelengths both inside and outside this wavelength range, to read "Visible and invisible laser radiation". If the product is classified on the basis of the level of visible laser radiation and also emits in excess of the AEL of Class 1 at invisible wavelengths, the label shall include the words "Visible and invisible laser radiation" in lieu of "Laser radiation".

I.13 Warning for visible laser radiation

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

I.14 Warning for LED radiation

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



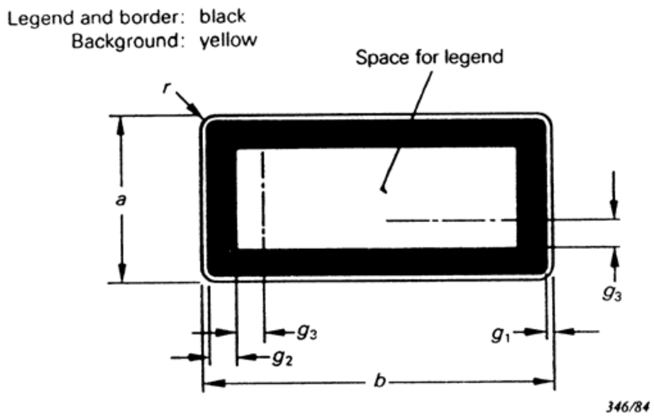
Dimensions in millimetres

a	g_1	g_2	r	D_1	D_2	D_3	d
25	0.5	1.5	1.25	10.5	7	3.5	0.5
50	1	3	2.5	21	14	7	1
100	2	6	5	42	28	14	2
150	3	9	7.5	63	42	21	3
200	4	12	10	84	56	28	4
400	8	24	20	168	112	56	8
600	12	36	30	252	168	84	12
The dimensions D_1, D_2, D_3, g_1 and d are recommended values.							

Note 1 The relationship between the greatest distance L from which the label can be understood and the minimum area A of the label is given by: $A = L^2 / 2000$, where A and L are expressed in square metres and metres respectively. This formula applies for distance L less than about 50 m.

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

Figure I.1 Warning label - Hazard symbol



Dimensions in millimetres

a x b	g_1	g_2	g_3	r	Minimum height of lettering
26 x 52	1	4	4	2	Lettering shall be of a size which renders it legible
52 x 105	1.6	5	5	3.2	
84 x 148	2	6	7.5	4	
100 x 250	2.5	8	12.5	5	
140 x 200	2.5	10	10	5	
140 x 250	2.5	10	12.5	5	
140 x 400	3	10	20	6	
200 x 250	3	12	12.5	6	
200 x 400	3	12	20	6	
250 x 400	4	15	25	8	
The dimension g_1 is recommended.					

Note 1 The relationship between the greatest distance L from which the label can be understood and the minimum area A of the label is given by: $A = L^2 / 2000$, where A and L are expressed in square metres and metres respectively. This formula applies for distance L less than about 50 m.

Note 2 These dimensions are recommended values. The label may be of any size necessary to contain the required lettering and border. The minimum width of each border dimension g_2 and g_3 shall be 0.06 times the length of the shorter side of the label.

Figure I.2 - Explanatory label

Abstracted from IEC 60825-1:2001

SUMMARY OF MANUFACTURER'S REQUIREMENTS

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

Annex K

DISPLAY LASER INFORMATION

1. Details of organisation / owner

    (a) Name : ____________________

    (b) Address : ____________________

    (c) Responsible Personnel : ____________________

    (d) Telephone : ____________________

    (e) Fax : ____________________

2. Details of the laser installation

    (a) Location : ____________________

    (b) Indoor/Outdoor : ____________________

    (c) Permanent/Temporary, Duration : ____________________

    (d) Date of installation : ____________________

    (e) Intended Purpose (e.g. stage performance, disco lighting, advertising) : ____________________

3. Details of organisation responsible for supply / installation of the laser system.

    (a) Name : ____________________

    (b) Address : ____________________

    (c) Responsible Personnel : ____________________

    (d) Telephone : ____________________

    (e) Fax : ____________________

4. Details of the laser equipment used

(a) Manufacturer : ______________________

(b) Model : ______________________

(c) Country of Origin : ______________________

(d) Class of Laser : ______________________

(e) Output Power : ______________________

⑥ Continuous Wave Mode ⑥ Pulse Mode

Wavelength	Maximum Power	Wavelength	Energy Per Pulse	Pulse Duration	Pulse Repetition Frequency
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______

(f) Output Beam Diameter : ______________________(mm)

(e) Beam Divergency : ______________________(sr)

5. Details of Operators

Name(s)	Trained Operator	Relevant Experience
______________	Yes / No	Yes / No
______________	Yes / No	Yes / No
______________	Yes / No	Yes / No
______________	Yes / No	Yes / No
______________	Yes / No	Yes / No

6. Two copies of sketch plan detailing the following should be provided
   (i) Location(s) of laser equipment used
   (ii) Location(s) of additional component used such as scanning head beam splitters, beam attenuators, beam stoppers, etc
   (iii) Location(s) of control panel(s)
   (iv) Beam path(s) / pattern
   (v) Position(s) of other reflective surface inside the display area (e.g. mirror, metal surface etc)
   (vi) Position(s) of barriers (if appropriate)
   (vii) Boundary of the laser display area(s)

7. Summary of laser display pattern(s)

   ____

   ____

8. Summary on the installation / operation of the laser system not mentioned in 6 & 7.

   ____

   ____

9. Calculations / measurements
   Sufficient information (including calculation) should be provided to demonstrate that the irradiance of the laser outside the boundary of the laser display area is below the MPE. If measured value(s) are given, the measuring method and instrument used should be stated.

10. Laser equipment catalogue if available.

Annex L

Abstracted from IEC 60825-1:2001

QUANTITIES, UNITS AND SYMBOLS

Quantity	Name of unit	Unit symbol	Definition
Length	metre millimetre micrometre nanometre	m mm µm nm	The metre is the length of the path travelled by light in a vacuum during a time interval of 1/229792458 of a second 10^{-3} m 10^{-6} m 10^{-9} m
Area	square metre	m^2	1 m^2
Mass	kilogram	kg	The mass equal to the mass of the international prototype of the kilogram
Time	second	s	The duration of 9192631770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state caesium-133 atom
Frequency	hertz	Hz	The frequency of a periodic phenomenon equal to one cycle per second
Plane angle	radian milliradian	rad mrad	The plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius 10^{-3} rad
Solid angle	steradian	sr	The solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere
Force	newton	N	1 $m.kg.s^{-2}$
Energy	joule	J	1 N.m
Radiant exposure	joule per square metre	$J.m^{-2}$	1 $J.m^{-2}$
Integrated radiance	joule per square metre per steradian	$J.m^{-2}.sr^{-1}$	1 $J.m^{-2}.sr^{-1}$
Power	watt	W	1 $J.s^{-1}$
	milliwatt	mW	10^{-3} W
Irradiance	watt per square metre	Wm^{-2}	1 Wm^{-2}
Radiance	watt per square metre per steradian	$W.m^{-2}.sr^{-1}$	1 $W.m^{-2}.sr^{-1}$
NOTE For convenience, multiples and submultiples of units have been included where appropriate			