

TECHNICAL REPORT

IEC TR 60825-10

First edition
2002-02

Safety of laser products –

Part 10: Application guidelines and explanatory notes to IEC 60825-1

Sécurité des appareils à laser –

Partie 10: Guide d'application et notes explicatives concernant la CEI 60825-1



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International Electrotechnical Commission, 3, rue de Varembe, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

**Part 10: Application guidelines and explanatory notes
to IEC 60825-1**

FOREWORD

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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 60825-10, which is a technical report, has been prepared by subcommittee 76: Optical radiation safety and laser equipment.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
76/217/CDV	76/229/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives.

This document, which is purely informative, is not to be regarded as an International Standard.

INTRODUCTION

This technical report is an informative document providing a simplified introduction to laser hazard concepts, classification, intrabeam viewing and extended source viewing used in IEC 60825-1, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide*.

This technical report does not replace IEC 60825-1; however, if there is any real or apparent conflict between this technical report and the standard, the standard must prevail.

SAFETY OF LASER PRODUCTS –

Part 10: Application guidelines and explanatory notes to IEC 60825-1

1 Scope

This technical report gives information on the physics relating to the dangers posed by laser products. It complements, but does not replace, the information in IEC 60825-1 by explaining the underlying principles. The application of this technical report is limited to laser products with finite accessible emissions of laser radiation.

2 Object

This technical report provides a user of IEC 60825-1 with background information for that standard (specifically the laser hazard, classification system, intrabeam viewing and extended source viewing), giving the user an insight into the physics behind that standard, so that the user may correctly interpret its requirements.

3 Reference documents

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1:1993, *Safety of laser products – Equipment classification, requirements and user's guide*¹

Amendment 1 (1997)

Amendment 2 (2001)

4 Definitions

For the purpose of this technical report, the definitions in IEC 60825-1 apply.

5 Why laser radiation is hazardous

Electromagnetic radiation is not normally considered dangerous. However, the simple analysis below shows that a 1 W laser can introduce more than five orders of magnitude greater light into the eye (at 1 m distance) than an incandescent bulb of equal power placed at the same distance, and more than one order of magnitude greater than that of the sun.

Laser radiation in the optical hazard region from 400 nm to 1 400 nm is focused to a small spot on the retina. This increases the hazard in that region. The current example illustrates the effect in the optical hazard region.

¹ There exists a consolidated edition (2001) that includes IEC 60825-1 (1993) and its Amendment 1 (1997) and Amendment 2 (2001).

Moreover, unlike the incandescent light bulb, laser light in the ocular hazard region may be focused to a small point on the retina measuring a few microns across. By comparison, the image of the sun on the retina would be of the order of 0,15 mm on the retina. The effect of an exposure to laser radiation could therefore be considerably worse than indicated by the analysis below.

Consider a *light bulb* producing 1 W of optical radiation (see Figure 1) typical of the interior light of a car. Light from the globe at 1 m has irradiance (power density) given by the power of the light globe divided by the surface area of a sphere whose radius is 1 m, as shown by the following equation:

$$\frac{1,0 \text{ W}}{4\pi(1,0 \text{ m})^2} = 8,0 \times 10^{-2} \text{ W} \cdot \text{m}^{-2} \quad (1)$$

NOTE The surface area of a sphere of radius r is given by $4\pi r^2$.

Compare this with radiation from a 1,0 W laser in the ocular hazard region with a 1 mm beam diameter at 1 m from the laser, with an approximate irradiance of:

$$\frac{1,0 \text{ W}}{\frac{\pi}{4} (1,0 \times 10^{-3} \text{ m})^2} = 1,3 \times 10^6 \text{ W} \cdot \text{m}^{-2} \quad (2)$$

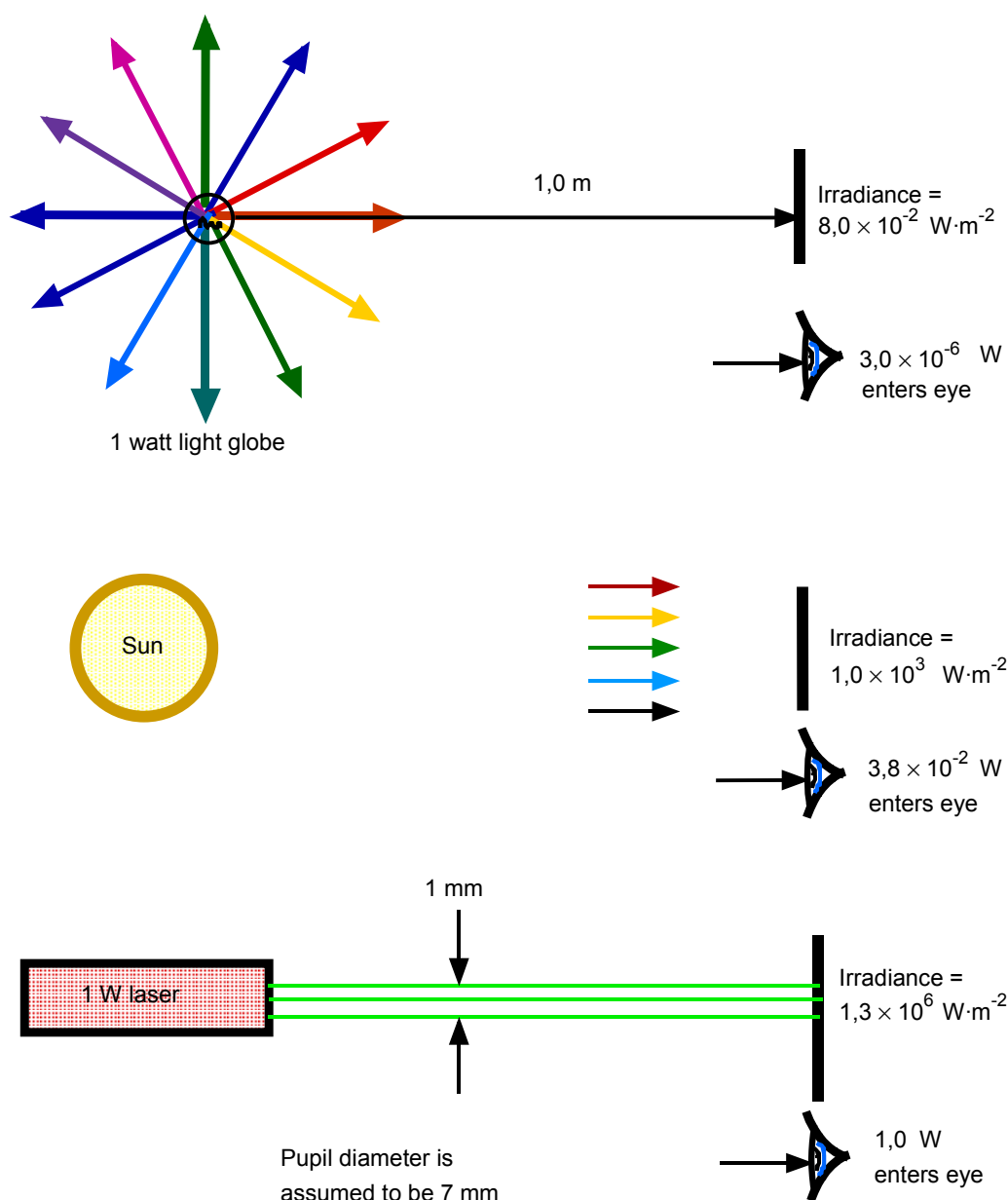
NOTE The area of a circle of diameter d is given by $\pi d^2/4$.

Throughout IEC 60825-1 it is assumed that the diameter of the pupil of the eye is 7 mm. This is a worst case occurring when the ambient light level is low. Under these circumstances the light from the globe entering a pupil having an area of:

$$\frac{\pi}{4} (7 \times 10^{-3})^2 = 3,8 \times 10^{-5} \text{ m}^2 \quad (3)$$

would be

$$(8,0 \times 10^{-2} \text{ W} \cdot \text{m}^{-2}) \times (3,8 \times 10^{-5} \text{ m}^2) = 3,0 \times 10^{-6} \text{ W} \quad (4)$$



IEC 571/02

Figure 1 – Comparison of the hazards of various light sources

Compare this with light entering the eye from a laser at 1 m. In the case of the laser with a beam diameter of 1 mm and small divergence, all of the light will enter an eye with a pupil diameter of 7 mm. This is $3,3 \times 10^5$ times as much light as would have entered the eye from a bulb producing the same amount of visible radiation.

The reason for this difference is shown diagrammatically in Figure 1.

The radiation from any source (including laser radiation with a wavelength between 400 nm and 1 400 nm) is generally focused on the retina, the light sensitive area at the back of the eye (see Figure 2). In the case of lasers, this may increase the irradiance (watts per square metre) of the light by approximately five orders of magnitude.

NOTE The anatomy of the human eye is shown in Figure B.1 of IEC 60825-1.

When a person 'looks at' an object, their eye is actually focusing that object on the fovea, where there is the highest density of cone receptor cells (see Figure 2). The fovea is only 1,5 mm or so in diameter and is the area on the retina generating our most acute vision. Images which need to be viewed in detail, such as the words on this page, are focused on the foveola which is only 350 microns in diameter. It is this section of the retina which is most at risk because of a natural tendency to 'look at' objects which attract our interest.

The highest risk is normally seen at the fovea because this is the location of gaze produced by the eye. It is also the section of the retina which has the most impact on visual function if damaged. Depending on the area of the foveola and the fovea damaged, reading may be precluded but individuals may still retain a measure of central and peripheral vision. Damage to the area surrounding the retina can occur with little loss of effective sight other than some reduction in peripheral vision which can occur without the affected person being aware of it.

The eye is remarkable in that it can detect light intensities varying over eight or nine orders of magnitude. Part of this accommodation is effected by changing the size of the pupil, but this only accounts for one order of magnitude. The change in pupil size occurs over a matter of seconds. When viewing in bright light, the fovea is active in discriminating small detail and colour, while the remainder of the retina provides peripheral vision, which primarily detects movement. As the light level reduces, the fovea becomes less important to vision and the remainder of the retina provides 'night vision'.

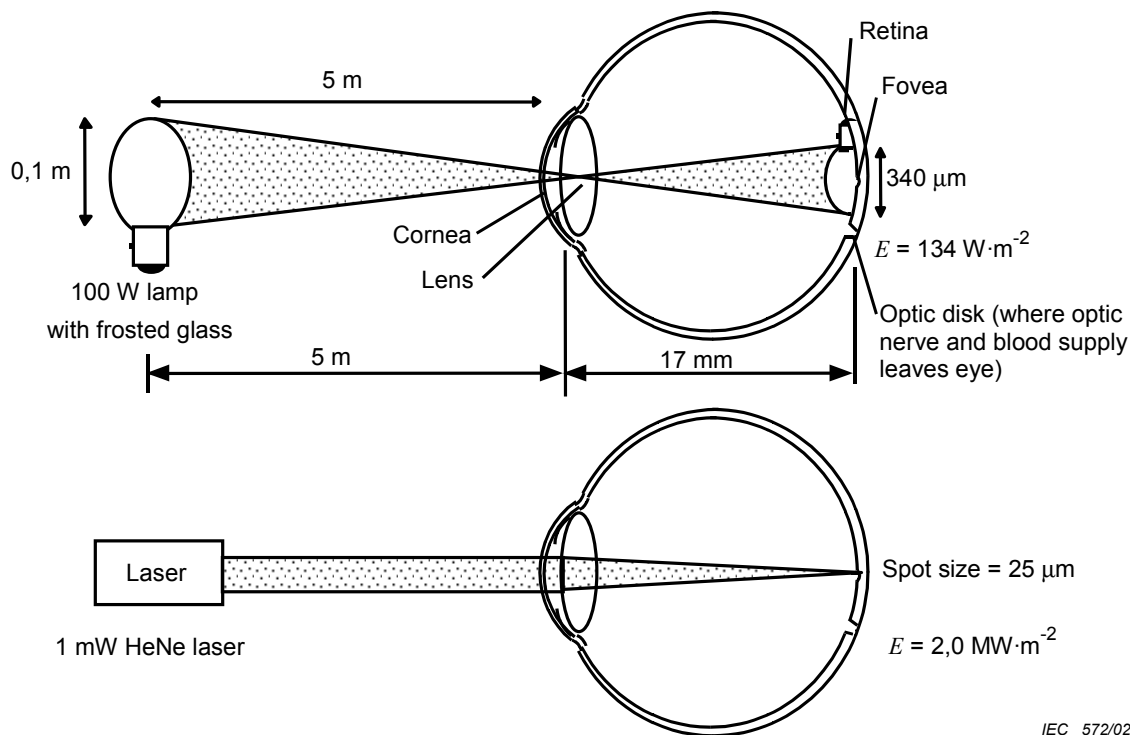


Figure 2 – Cross-section of eye showing comparison of the irradiance at the retina for an image of a lamp with an output of 100 W and an ideal diffraction limited spot from a 1 mW HeNe laser

Damage to tissues can be caused by heat effects, thermo-acoustic transients, or photo-chemical processes. The degree to which these effects are responsible for damage depends on the physical parameters relating to the exposure.

NOTE The various mechanisms for damage are shown in Figure B.2 of IEC 60825-1.

Radiation from laser products can cause different effects depending on the wavelengths and energy density of the radiation, and the part of the body exposed to the radiation.

NOTE See Figure B.3 of IEC 60825-1.

Hazards include absorption by and damage to the skin and the eye, setting fire to clothes and other materials. The full range of hazards needs to be considered.

In assessing the hazard, a number of laser parameters are of importance. These include:

- a) exposure duration;
- b) pulse width;
- c) wavelength;
- d) CW or pulsed operation;
- e) repetition rate, if applicable;
- f) beam diameter;
- g) beam divergence; and
- h) viewing distance.

The hazard is often increased by telescopes or binoculars because they can gather additional radiation and concentrate it in the eye. These parameters are discussed in detail in later sections.

6 Units

Table 1 lists the common units and their symbols used in IEC 60825-1. Examples of these quantities are given diagrammatically in Figure 3.

7 Maximum permissible exposures (MPEs)

IEC 60825-1 relies on the concept of maximum permissible exposures (MPEs). The MPEs are derived primarily from animal and human data, but take account of human variability and laser parameters. MPE levels are set by ICNIRP (International Commission on Non-Ionising Radiation Protection). They are reevaluated from time to time in the light of available evidence.

Clause 3.51 of IEC 60825-1 defines the maximum permissible exposure as “That level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately after, or after a long time, and are related to the wavelength of the radiation, the pulse duration or exposure time, the tissue at risk and, for visible and near infra-red radiation in the range of 400 nm to 1 400 nm, the size of the retinal image. Maximum permissible exposure levels are (in the existing state of knowledge) specified in clause 13 (of IEC 60825-1).”

MPEs are expressed as irradiance or radiant exposure at the cornea, and are given as tables in IEC 60825-1. MPEs for ocular exposure at the cornea are tabulated in Table 6 of IEC 60825-1 as a function of wavelength and exposure time. Table 8 of IEC 60825-1 tabulates the MPE of skin to laser radiation.

The MPE values should be used as guides in the control of exposures and should not be regarded as precisely defining the dividing lines between safe and dangerous levels. In any case, exposure to laser radiation shall be as low as possible.

Note that while the probability of an exposure at the level of the MPE causing eye damage is very low, it may not be zero. Because of this, and the uncertainty in the derivation of MPEs, it is good practice to avoid all unnecessary exposure to laser radiation at levels that approach the MPE.

The biophysical effects of laser radiation are described in detail in Annex B of IEC 60825-1. Thermal effects are those which occur when sufficient radiation energy has been absorbed by a biological system to cause heating in the system. Most laser damage is due to the heating of the absorbing tissue or tissues.

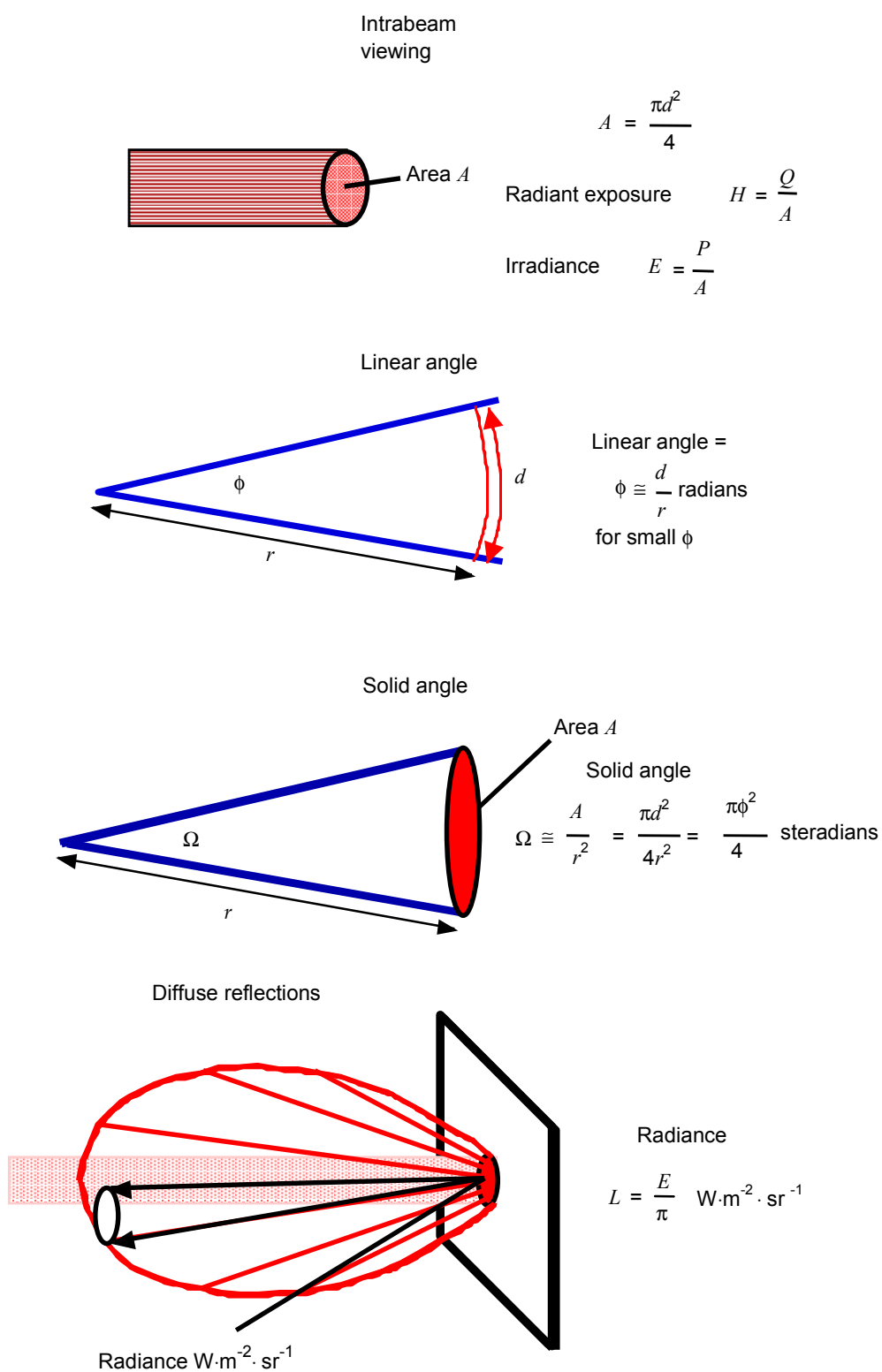
On the other hand, at certain wavelengths, photochemical effects or those caused by the specific molecular absorption of a given radiation can lead to tissue damage. Following the absorption, the molecule may undergo a chemical reaction unique to its excited state. This photochemical reaction is believed to be responsible for damage at low levels of exposure. By this mechanism, some biological tissues such as the skin, and the lens of the eye, may show irreversible changes induced by prolonged exposure to moderate levels of UV radiation and short wavelength radiation. For this reason the MPEs are correspondingly lower than for wavelengths where the mechanism is thermal.

In Table 6 of IEC 60825-1 a calculation of both the retinal photochemical hazard levels and the retinal thermal hazard levels is required for exposures greater than 10 s of radiation with a wavelength between 400 nm and 600 nm and for exposures greater than 1,0 s of radiation with a wavelength between 400 nm and 484 nm. In these cases the most restrictive hazard level becomes the MPE.

In some cases, laser products produce radiation comprising multiple wavelengths. The multiple wavelengths may affect similar tissue. For example there may be more than one wavelength contributing to heat generation in the retina. Alternatively each wavelength may operate independently. Table 5 of IEC 60825-1 provides a guide to determine whether the hazardous effects of one or more wavelengths are additive or whether each should be treated separately.

Table 1 – Commonly used units and symbols

Quantity	Unit	Abbreviation	Symbol	Formulae
Area	Square metre	m ²	<i>A</i>	See Figure 3
Exposure time	Second	s	<i>T</i>	—
Integrated radiance	Joule per square metre per steradian	J m ⁻² sr ⁻¹	<i>L</i> ^b	$L = H/\Omega$ ^a
Irradiance	Watt per square metre	W m ⁻²	<i>E</i>	$E = P/A$
Linear angle	Radian	rad	ϕ	See Figure 3
Radiance	Watt per square metre per steradian	W m ⁻² sr ⁻¹	<i>L</i> ^b	$L = E/\Omega$ ^a
Radiant energy	Joule	J	<i>Q</i>	$Q = PT$
Radiant exposure	Joule per square metre	J m ⁻²	<i>H</i>	$H = Q/A$
Radiant power	Watt	W	<i>P</i> , Φ	$P = Q/T$
Solid angle	Steradian	sr	Ω	See Figure 3
^a In this case <i>H</i> (or <i>E</i>) is the radiant exposure (or irradiance) measured at the diffuse reflector or divergent source. Ω is the solid angle into which the radiation is directed.				
^b <i>L</i> is used for both integrated radiance and radiance in different parts of IEC 60825-1				



IEC 573/02

Figure 3 – Commonly used units

8 The classification system

8.1 Laser product classification

The product classification is the primary indication of whether the laser product is capable of causing injury. It is the responsibility of the manufacturer to label and provide information about its laser product in accordance with Section 2 of IEC 60825-1. A guide for the implementation of safe practice for the user is set out in Section 3 of IEC 60825-1. It is therefore necessary that both the manufacturer and, where a hazard exists, the user, understand the system of classification. The details of the classification system are set out in Section 2 of IEC 60825-1, and the philosophy behind it is described below.

The classification of a laser product is based on the radiation emitted during the normal operation and any reasonably foreseeable fault condition for that product. In some cases the removal of protective shielding or access panels may lead to the possibility of an exposure in excess of that allowable for that class of laser. Such panels should be clearly marked by the manufacturer, and should only be removed by persons with the appropriate level of knowledge and training in laser safety.

In the process of taking the measurements required for classification, the concept of measurement aperture is used. The size of the spot on the retina will depend on a number of factors including the diameter of the beam, and whether the beam is focused on the retina. The worst case (that is the smallest retinal spot) is one for which the beam just fills the pupil (assumed to be of 7 mm diameter) and the beam is accurately focused. For this reason, when the MPE is specified as an irradiance ($\text{W}\cdot\text{m}^{-2}$) it is assumed that, if the beam is less than 7 mm its power should be averaged over 7 mm. That is, it should be assumed that the beam is expanded to 7 mm diameter. If the beam diameter is greater than 7 mm, only that power entering a 7 mm aperture should be considered. The same principle applies if the MPE is expressed as a radiant exposure ($\text{J}\cdot\text{m}^{-2}$).

The measurement procedures for classification are specified in IEC 60825-1. The procedures specify a range of measurement apertures which vary with wavelength and the class of laser and which relate to the diameter of the pupil and the assumed diameter of viewing optics, or in some cases a limiting aperture is specified for measurement convenience and standardization.

The limits used for classification are called accessible emission limits (AELs). They are derived from the MPEs using limiting apertures and are expressed either as a power limit, an energy limit, an irradiance limit, a radiant exposure limit, or a combination of these.

A laser is correctly classified if its parameters exceed those of the next lower class, and are less than or equal to the limits of its class.

NOTE Because the AELs are based on MPEs, the classification system is an indication of whether the laser product is likely to cause injury. An exposure to visible laser radiation less than that required to cause injury may still be uncomfortable and cause temporary blindness or distraction. For this reason all exposure to laser radiation should be as low as possible.

8.1.1 Class 1 and 1M laser products

Class 1 laser products are safe under reasonably foreseeable conditions of operation. In general they would not allow exposure to sufficient radiant energy to damage the eye or skin. The AELs for Class 1 laser products are set out in Table 1 of IEC 60825-1.

Class 1M laser products are safe under reasonably foreseeable conditions of operation provided that they are not viewed with magnifying optics of any kind. Class 1M usually relates to laser products with high divergence or large beam diameters compared to the limiting aperture.

Magnifying optical instruments are designed to magnify the image on the retina. See 9.5 for more details.