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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.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

$$\frac{1{,}0\ \text{W}}{4\pi(1{,}0\ \text{m})^2} = 8{,}0\times10^{-2}\ \text{W}\cdot\text{m}^{-2} \tag{1}$$

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:

$$\frac{1{,}0\ \text{W}}{\frac{\pi}{4}\left(1{,}0\times10^{-3}\ \text{m}\right)^2} = 1{,}3\times10^{6}\ \text{W}\cdot\text{m}^{-2} \tag{2}$$

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:

$$\frac{\pi}{4}\left(7\times10^{-3}\right)^2 = 3{,}8\times10^{-5}\ \text{m}^2 \tag{3}$$

would be

$$(8{,}0\times10^{-2}\ \text{W}\cdot\text{m}^{-2})\times(3{,}8\times10^{-5}\ \text{m}^2) = 3{,}0\times10^{-6}\ \text{W} \tag{4}$$

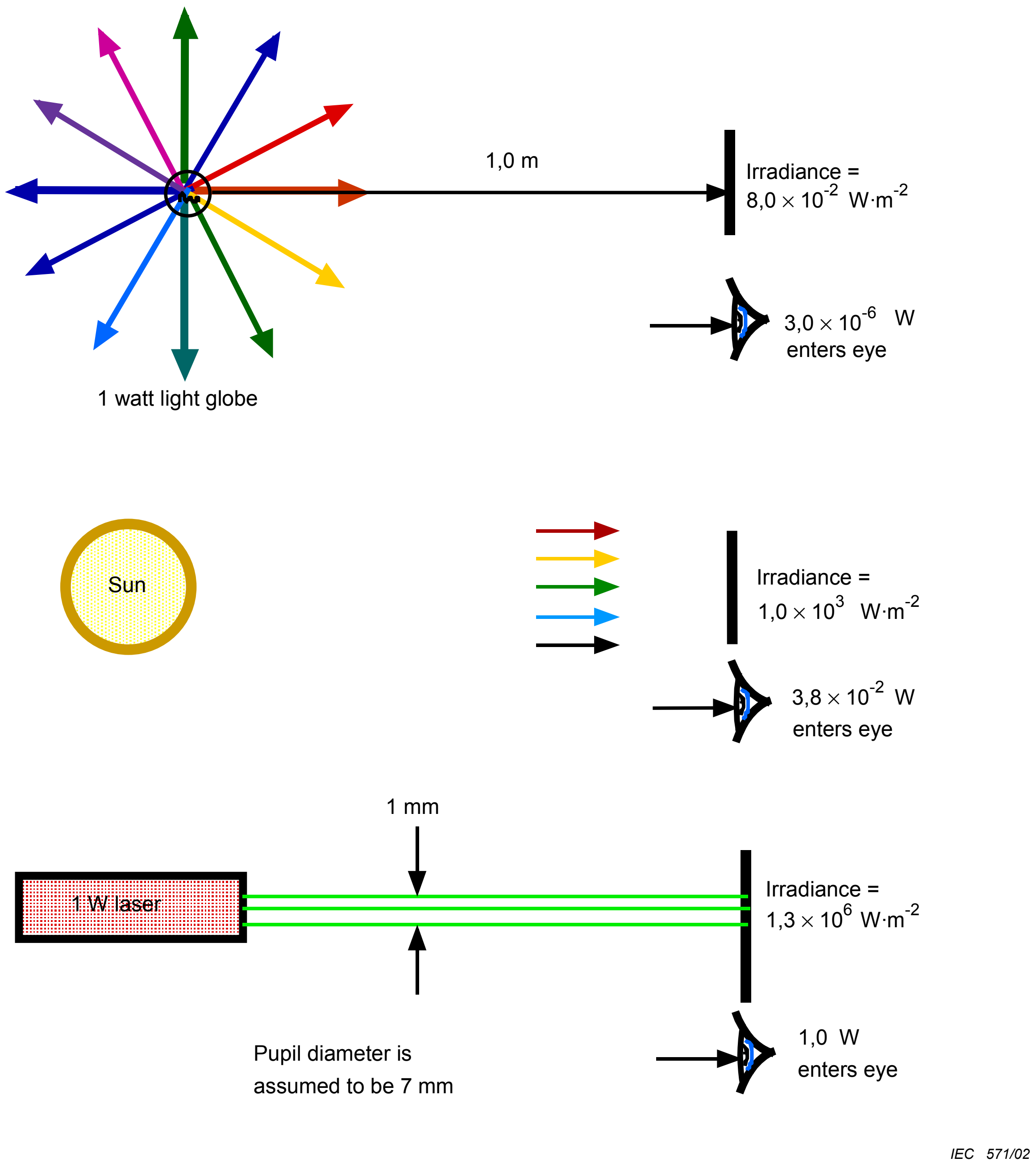



**Figure 1 – Comparison of the hazards of various light sources**

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'.



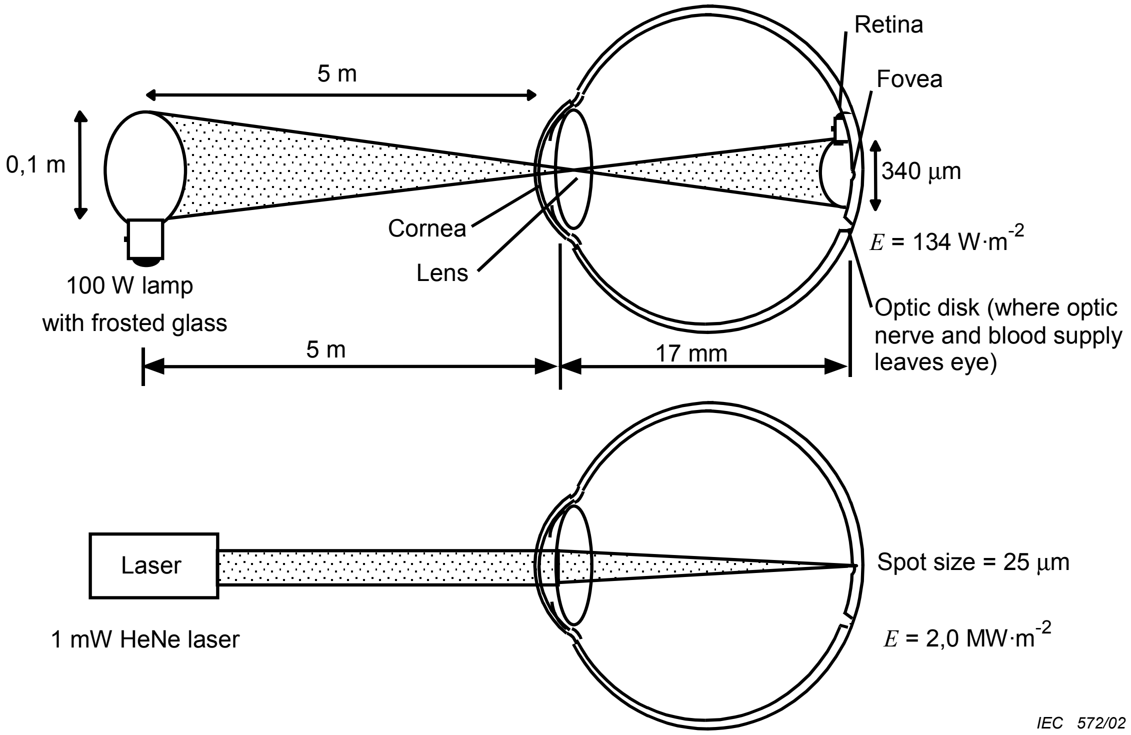



**Figure 2 – Cross-section of eye showing comparison of the irradiance at the retina for an image of a lamp with an output of 100 W and an ideal diffraction limited spot from a 1 mW HeNe laser**

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 a 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 | $m^2$ | $A$ | See Figure 3 |
| Exposure time | Second | s | $T$ | — |
| Integrated radiance | Joule per square metre per steradian | $J\ m^{-2}\ sr^{-1}$ | $L$[b] | $L = H/\Omega$ [a] |
| Irradiance | Watt per square metre | $W\ m^{-2}$ | $E$ | $E = P/A$ |
| Linear angle | Radian | rad | $\phi$ | See Figure 3 |
| Radiance | Watt per square metre per steradian | $W\ m^{-2}\ sr^{-1}$ | $L$[b] | $L = E/\Omega$ [a] |
| Radiant energy | Joule | J | $Q$ | $Q = PT$ |
| Radiant exposure | Joule per square metre | $J\ m^{-2}$ | $H$ | $H = Q/A$ |
| Radiant power | Watt | W | $P$, $\Phi$ | $P = Q/T$ |
| Solid angle | Steradian | sr | $\Omega$ | See Figure 3 |

[a] In this case $H$ (or $E$) is the radiant exposure (or irradiance) measured at the diffuse reflector or divergent source.
$\Omega$ is the solid angle into which the radiation is directed.

[b] $L$ is used for both integrated radiance and radiance in different parts of IEC 60825-1

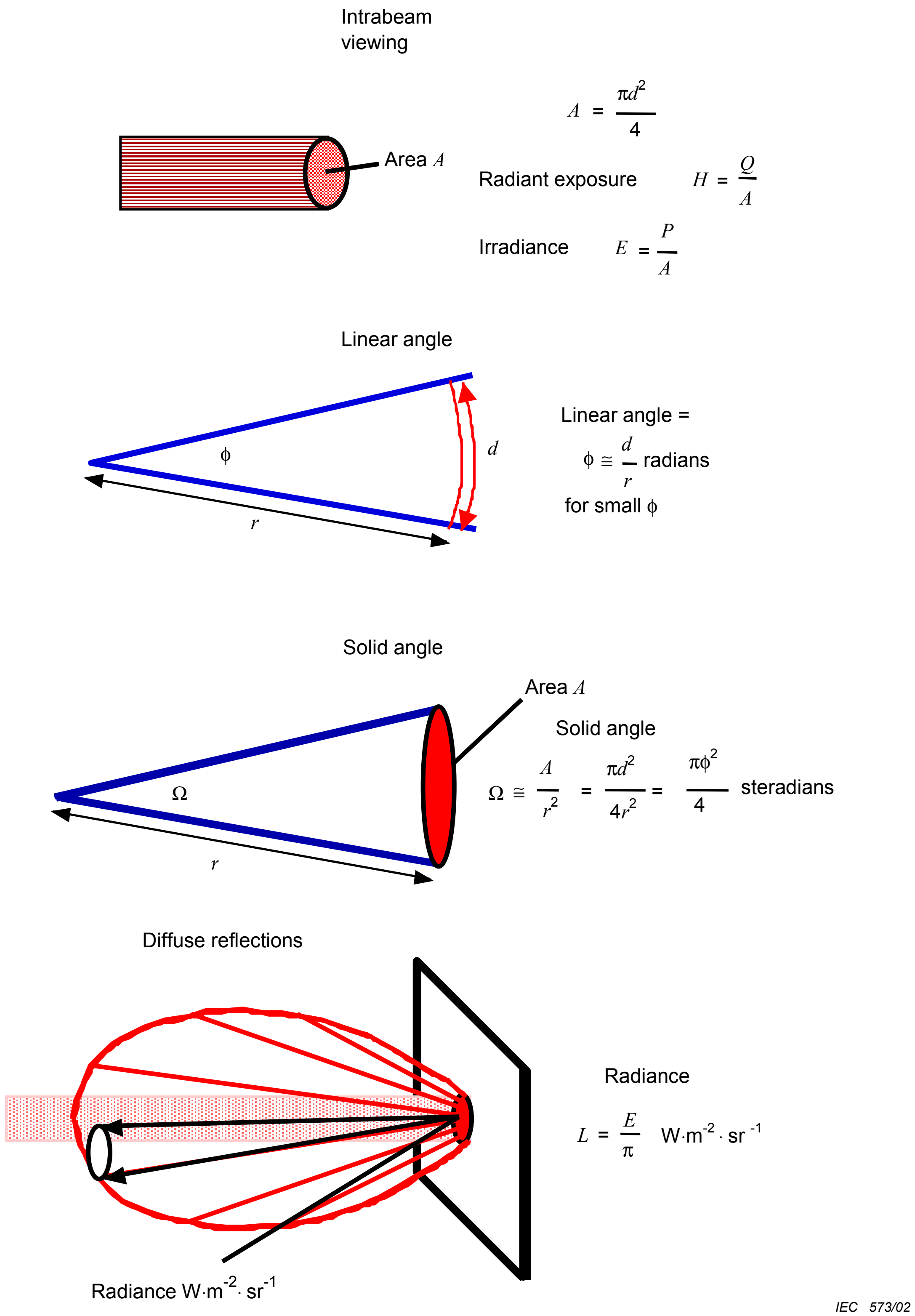



**Figure 3 – Commonly used units**

# 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 measurement*s* 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 ($W \cdot m^{-2}$) 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 7mm 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 ($J \cdot m^{-2}$).

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 an 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.

#### 8.1.2 Class 2 and 2M laser products

Class 2 laser products would not cause permanent damage to the eye under reasonably foreseeable conditions of operation, provided that any exposure can be terminated by the blink reflex (assumed to take 0,25 s). Because classification assumes the blink reflex, only laser products with a visible output (400 nm to 700 nm wavelengths) can be classified as Class 2. The MPE for visible radiation for 0,25 s is 25 $W \cdot m^{-2}$. This irradiance is equivalent to 1 mW entering an aperture of 7 mm diameter (the assumed size of the pupil).

Thus the AEL for Class 2 laser products is 1,0 mW for collimated beams or beams from small sources. This can be seen in Table 2 of IEC 60825-1. Note that the parameter $C_6$ equals 1 for well-collimated beams, as indicated in the notes to Tables 1 to 4 of IEC 60825-1. $C_6$ takes on another value for extended sources, and this is discussed in detail in Clause 10 of this technical report.

Class 2 laser products are not hazardous as long as staring at them is not a requirement of their design. However, they may cause flash blindness. The use of viewing optics such as binoculars with Class 2 laser products does not usually create a hazard as long as the objective lens diameter is not greater than 50 mm.

In the case of Class 2M laser products, a hazard may exist if they are viewed through magnifying optics such as eye loupes, binoculars or telescopes.

#### 8.1.3 Class 3R laser products

Class 3R laser products emit radiation 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.

#### 8.1.4 Class 3B laser products

Class 3B laser products are unsafe for eye exposure at all wavelengths, but are generally not so powerful that a short exposure would damage skin. Usually only ocular protection would be required. Diffuse reflections are safe if viewed for less than 10 s. Table 4 in IEC 60825-1 shows the AELs for Class 3B laser products.

#### 8.1.5 Class 4 laser products

Class 4 laser products are generally powerful enough to burn skin and cause fires and may ionise the atmosphere when focused. As such, a range of additional safety measures are required.

#### 8.1.6 Product modification

If the user of a laser product makes changes to the product or does not use it in the manner intended by the manufacturer, reclassification may be required. Under these circumstances the person or organization that modifies the laser product takes on the responsibilities of a manufacturer (see 4.1.1 of IEC 60825-1).

### 8.2 Procedures for hazard control

The procedures for hazard control are set out in Clause 12 of IEC 60825-1. The primary considerations include the capacity of the laser product to cause injury (as indicated broadly by its classification), the environment in which it is used and the level of knowledge of people who might be exposed.

Where a hazard is likely to exist, a laser safety officer (LSO) should be appointed. It is the LSO's responsibility to evaluate the hazard and establish appropriate procedures.

Safe operation of Class 3B and Class 4 laser products outdoors relies on the concept of nominal ocular hazard distance, which is discussed in Clause 9.

Class 3B laser products need to be operated in a controlled area, with appropriate beam stops and with precautions taken to prevent unintended specular reflections. Eye protection is required if there is any possibility of exposure. Diffuse reflections are safe, provided the distance between the diffusely reflecting screen and the observer exceeds 130 mm and the exposure does not exceed 10 s.

For Class 4 laser products additional precautions are required. Beams can cause fires and injuries to the skin as well as eye injuries. Beam paths should be enclosed and the area should be restricted to properly trained and protected personnel during operations. Remote control should be used where practicable, there should be good room illumination and eye protection should be worn. Fire resistant materials should be used as backstops. Special precautions should be taken for lasers radiating at invisible wavelengths.

In choosing eye protection, the degree of protection should be considered. Laser eye protectors are rated according to their "optical density" ($D_\lambda$) defined as:

$$D_\lambda = \log_{10}\frac{H_0}{MPE} \tag{5}$$

where $H_0$ is the expected radiant exposure at the unprotected eye.

This equation is used when the MPE is in units of J·m$^{-2}$. In cases where the MPE is in W·m$^{-2}$, the following form should be used:

$$D_\lambda = \log_{10}\frac{E_0}{MPE} \tag{6}$$

where $E_0$ is the expected irradiance at the unprotected eye.

The units of MPE determine whether $H_0$ or $E_0$ should be used.

The major considerations include:

a) wavelengths of operation;
b) radiant exposure or irradiance;
c) MPE;
d) optical density;
e) visible radiation transmission requirements;
f) the exposure level at which damage to the eyewear occurs;
g) need for prescription glasses;
h) comfort and ventilation;
i) degradation;
j) strength;
k) peripheral vision requirements.

In cases where eye protection would otherwise be required, operations should only be undertaken with the approval of the laser safety officer. More detailed information on hazard identification as well as guidance on the selection of appropriate laser eye protectors is given in IEC 60825-1.

# 9 Intrabeam viewing

## 9.1 General

For a given amount of radiant power or energy entering the eye, one might expect the damage threshold to depend on the size of the image focused onto the retina in the case of thermal hazards. Paradoxically, this only occurs when the angle subtended at the eye by the source, $\alpha$ (see Figure 4) exceeds the coefficient called $\alpha_{min}$ (equal to 1,5 mrad) in IEC 60825-1. At angular subtenses less than $\alpha_{min}$ damage thresholds are determined by the total energy or power entering the eye and not by the irradiance or radiant exposure of the retinal image.

This effect results from the fact that, for small retinal image sizes, tissue cooling is dominated by radial conduction from the centre of the image formed on the retina. Although the heating rate of individual cells reduces with increasing image size, the lengthening of the radial cooling path from the centre of the image means that the cells in the image centre sustain a temperature rise for a given exposure time which is constant for a range of image sizes. This exposure condition is referred to as 'point source viewing'.

At angular subtenses above $\alpha_{min}$, "extended source viewing" conditions apply. Cooling into the vitreous humour gradually becomes the dominant cooling mechanism. Consequently, damage processes become dependent on the image size and, therefore, on the value of angular subtense. This is the basis for the coefficient $C_6$ in IEC 60825-1.

At angular subtenses above $\alpha_{max}$, damage thresholds depend upon the radiance or integrated radiance of the image as described in 10.2.

As far as IEC 60825-1 is concerned, for all $\alpha > \alpha_{min}$ extended source viewing conditions exist. For all $\alpha < \alpha_{min}$ point source or intrabeam viewing exists.

All laser beams diverge or converge to some extent. In the case of Class 3B and Class 4 laser products, the MPE is exceeded at the output of the laser. For a laser beam the irradiance ($W{\cdot}m^{-2}$) and the radiant exposure ($J{\cdot}m^{-2}$) generally decrease as the cross-sectional area of the beam increases with increasing distance from the source. This is shown in Figure 5.

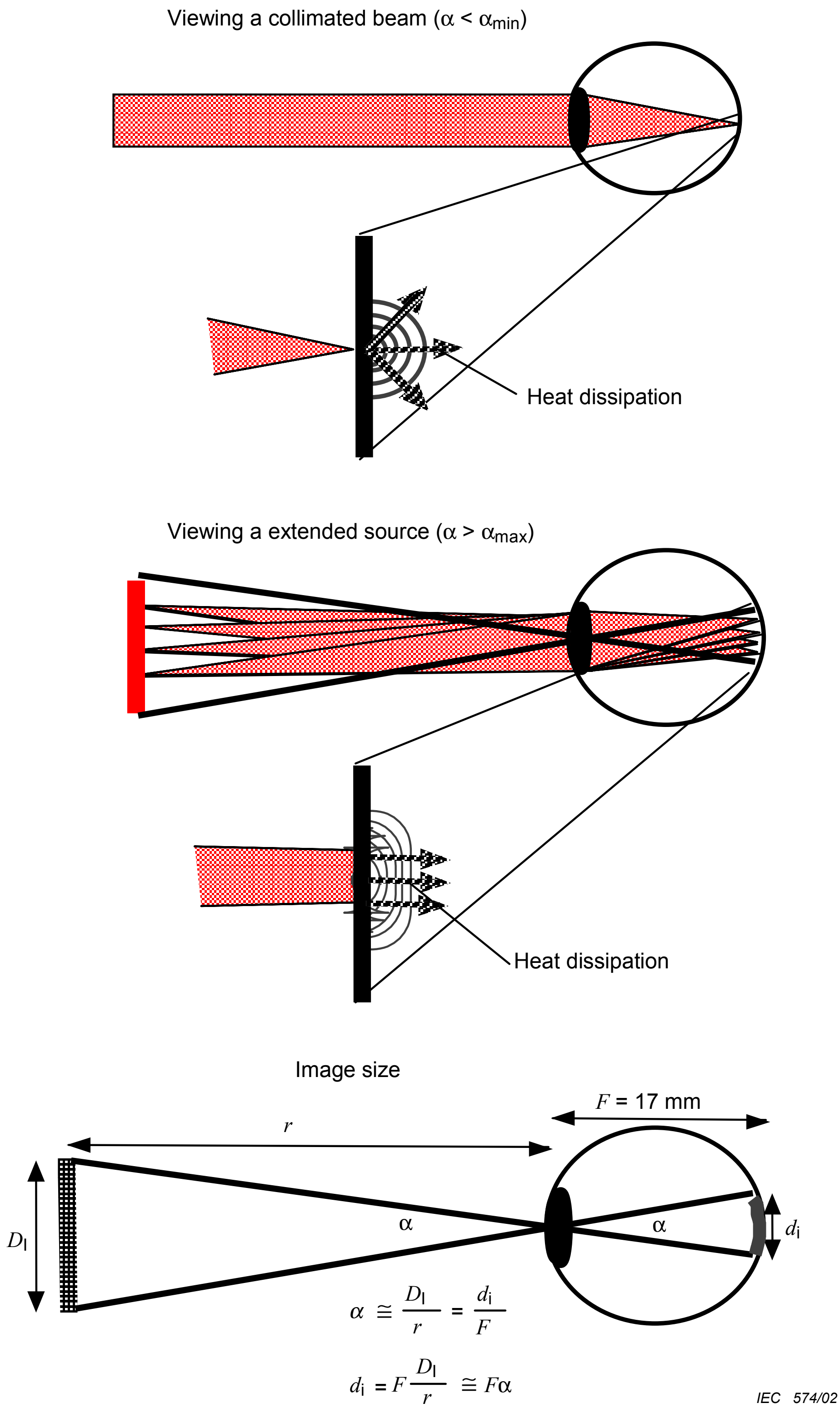
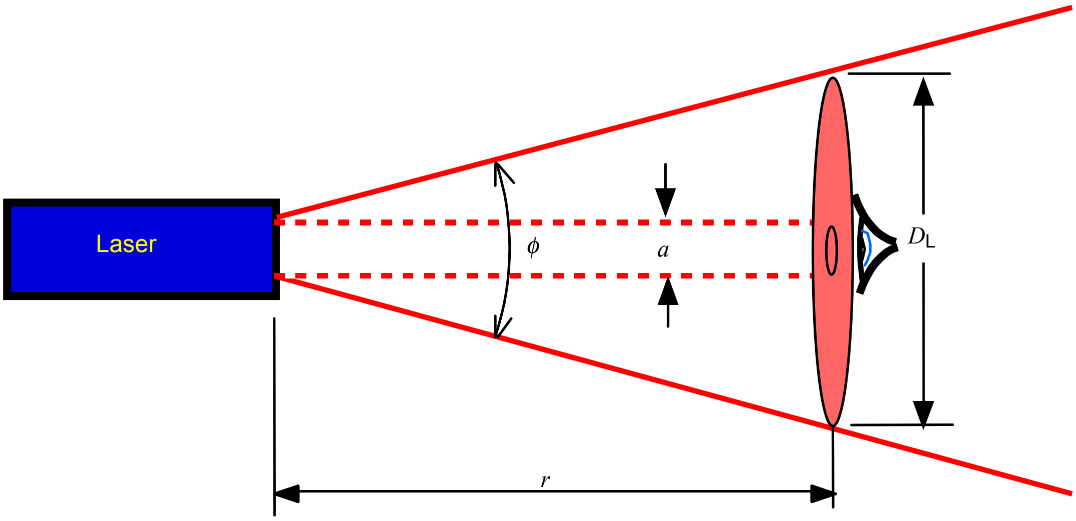



**Figure 4 – Angular subtense, retinal cooling and image size for wavelengths in the retinal hazard region**




Diameter, $D_L = r\phi + a$

Area, $A = \frac{\pi D_L^2}{4}$

Irradiance, $E = \frac{Power}{A}$

Radiant exposure, $H = \frac{Energy}{A}$

IEC 575/02

**Figure 5 – Divergence of laser radiation without an external beam waist**

It may be necessary to determine whether a potential exposure at some distance $r$ from the laser would be hazardous (see Figure 5). This can be done by comparing the actual exposure with the relevant MPE. The first step is to determine the MPE for the wavelength and the likely exposure time. Taking the simplest case of a visible CW laser, the MPE can be determined from Table 6 of IEC 60825-1. The determination of MPEs for pulsed lasers is discussed in detail in 9.4.

This derivation only applies to beams which diverge from the laser in the far field region of the beam. For beams which converge to a waist external to the laser a more accurate analysis beyond the scope of this document is required.

The MPE will be in units of either W·m$^{-2}$ or J·m$^{-2}$. If the MPE is in units of W·m$^{-2}$ the radiation output of the laser product in watts should be determined. If the MPE is in units of J·m$^{-2}$ the radiation output of the laser in joules should be determined. This can be done with the following equations:

$$P = \frac{Q}{t} \tag{7}$$

or

$$Q = P \times t \tag{8}$$

where:

$P$ is the power, in watts

$Q$ is the energy, in joules, and

$t$ is the time for $Q$ to be delivered, in seconds.

The output of the laser product in watts or joules, should be divided by the area of the beam at the observer to obtain the irradiance (in $W \cdot m^{-2}$) or the radiant exposure (in $J \cdot m^{-2}$). If the exposure exceeds the MPE then the exposure should be avoided. If the diameter of the beam at the distance $r$ is less than the limiting aperture (7 mm for a laser radiation between 400 nm and 1 400 nm), the beam should be assumed to have a diameter equal to the limiting aperture (see 8.1).

NOTE When comparing any exposure to a MPE, it is essential that the units in which the exposure is be identical to those of the MPE.

On occasions it may be necessary to convert irradiance to radiant exposure and vice versa, This can be achieved as follows:

$$E = \frac{H}{t} \tag{9}$$

or

$$H = E \times t \tag{10}$$

where

$E$ is the irradiance, in watts per square metre,

$H$ is the radiant exposure, in joules per square metre, and

$t$ is the time, in seconds.

An alternative approach is to determine the distance from the laser product at which an exposure is just below the MPE. This is called he nominal ocular hazard distance (NOHD). At smaller distances the exposure will exceed the MPE.

### 9.2 Nominal ocular hazard distance (NOHD)

In the analysis of point source viewing conditions, the concept of NOHD is used and is related to that of MPE. The NOHD is the nominal distance at which the exposure equals the MPE.

The concept of NOHD is used when laser products such as range finders or display lasers are to be used in the open air. It represents the distance within which exposure exceeds the MPE and eye protection is required.

Assuming linear divergence, from Figure 6 and the definition of the angle $\phi$ it is evident that:

$$D_{\mathrm{NOHD}} = NOHD \times \phi + a \tag{11}$$

where:

$D_{\mathrm{NOHD}}$ is the diameter of the beam at the NOHD,

$a$ is the diameter of beam at the exit from the laser, and

$\phi$ is the divergence angle.

NOTE In 3.10 of IEC 60825-1 the beam diameter is defined as the diameter of the smallest circle which contains 63% of the total beam energy. In the case of a Gaussian beam the diameter is the distance between two opposite points at which the irradiance or radiant exposure has fallen to 1/e of its peak value.

The area of the beam at the NOHD ($A_{\mathrm{NOHD}}$) is given by the following equation:

$$A_{\mathrm{NOHD}} = \frac{\pi \times D_{\mathrm{NOHD}}{}^2}{4} \tag{12}$$

The irradiance at the NOHD ($E_{NOHD}$) is given by the following equation:

$$E_{NOHD} = \frac{P}{A_{NOHD}} = \frac{4 \times P}{\pi \times D_{NOHD}{}^2} = MPE \qquad (13)$$

where

$P$ is the radiant power of the laser, and

$D_{NOHD}$ is the diameter of the beam at the NOHD.

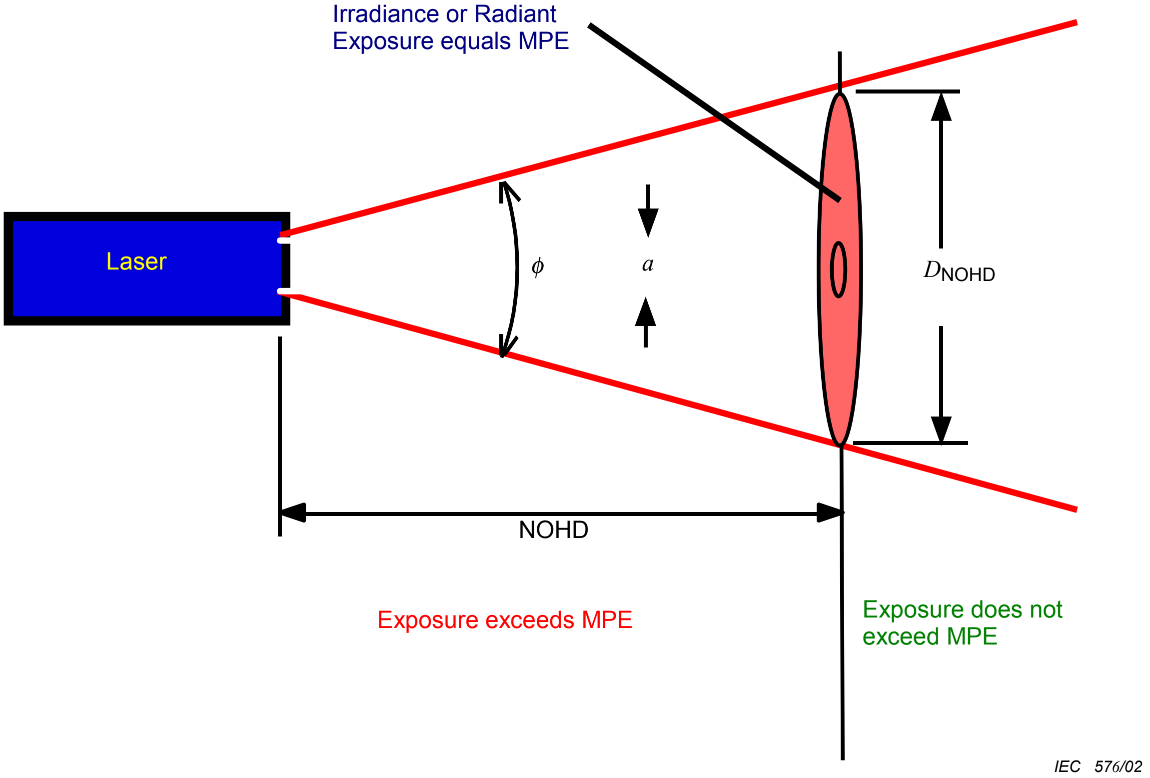



**Figure 6 – The concept of nominal ocular hazard distance**

Replacing $D_{NOHD}$ with ($NOHD \times \phi + a$) from equation 11 gives:

$$MPE = \frac{4 \times P}{\pi \times (NOHD \times \phi + a)^2} \qquad (14)$$

where

$a$ is the diameter of the beam at the exit from the laser, and

$P$ is the radiant power of the laser.

Rearranging this equation to obtain NOHD explicitly gives:

$$NOHD = \frac{1}{\phi}\left[\frac{4 \times P}{\pi \times MPE}\right]^{0,5} - \frac{a}{\phi} \qquad (15)$$

where

$P$ is the radiant power of the laser,

$a$ is the diameter of the beam at the exit from the laser, and

$\phi$ is the beam divergence angle.

The above equations are approximations applicable to a generalized situation. [2]

If $a$ is small compared to the term in square brackets in equation 15, it can conservatively be neglected.

If $a$ is not small and the calculated NOHD is negative, the result indicates that the laser is safe for that exposure at all distances.

The above formula relates to laser products with Gaussian beams. For laser products of unknown mode structure, a factor is introduced to account for possible `hot spots' in the beam. This matter is referred to in Annex A5 of IEC 60825-1. In this technical report the factor is given the symbol $k$. For beams of unknown mode structure it has the value of 2,5. If the mode structure is known to be Gaussian, then $k$ = 1.

If the mode structure is known and is non-Gaussian, the appropriate value for $k$ should be determined. The full equation then becomes:

$$NOHD \approx \frac{1}{\phi}\left[\frac{4 \times k \times P}{\pi \times MPE(\mathrm{W \cdot m^{-2}})}\right]^{0,5} - \frac{a}{\phi} \qquad (16)$$

where $P$ is the radiant power produced by the laser.

This formula has been derived for the case where the MPE of the laser is given as an irradiance ($\mathrm{W \cdot m^{-2}}$). In cases where the MPE is given as a radiant exposure, the corresponding NOHD equation is:

$$NOHD \approx \frac{1}{\phi}\left[\frac{4 \times k \times Q}{\pi \times MPE(\mathrm{J \cdot m^{-2}})}\right]^{0,5} - \frac{a}{\phi} \qquad (17)$$

The preceding equations form the basis of the calculation of NOHD. In cases where the second term can (conservatively) be ignored, a further approximation can be obtained as follows:

$$NOHD \approx \frac{1{,}784}{\phi}\sqrt{\frac{P}{MPE}} \quad \text{for } k = 2{,}5\text{; and} \qquad (18)$$

$$NOHD \approx \frac{1{,}128}{\phi}\sqrt{\frac{P}{MPE}} \quad k = 1 \text{ for Gaussian beams.} \qquad (19)$$

The above two equations are true for MPEs in $\mathrm{W \cdot m^{-2}}$. If the stated MPE is in $\mathrm{J \cdot m^{-2}}$ then the $P$ in watts should be replaced by $Q$ in joules.

[2] For Gaussian beam propagation, more exact equations are given in KOLGENICK, H. and LI, T. Laser Beams and Resonators. *Appl. Opt.*, 1996, **5**, p.1550–1567 and *Proc IEEE*, 1996, **54**(10), p.1312–1329.

### 9.3 NOHD calculation – CW output

For Class 3R, Class 3B and Class 4 laser products it may be necessary to calculate the NOHD. Flowchart 1 of Annex A describes a technique for calculating the NOHD for a product with a CW output. The first step is to tabulate the relevant parameters (box 2). Since the MPE depends on the maximum likely exposure time it is necessary to determine an exposure time consistent with the standard. The MPE should be determined for each wavelength, using the appropriate exposure time in Table 6 of IEC 60825-1 (box 3). If only one wavelength is involved (box 4A) the MPE can be determined from Table 6 of IEC 60825-1. The NOHD can then be calculated from the appropriate formula in 9.2. Allowances for the possible use of optical viewing aids are discussed in 9.5.

The process for calculating the MPE becomes more complicated when the laser produces radiation in multiple wavelengths. If this is the case, Table 5 of IEC 60825-1 should be consulted. The matrix indicates which wavelength bands should be added.

Usually, if radiation of two wavelengths is absorbed in the same body tissue then the effects are additive. Wavelengths in the infrared B and ultraviolet A are an example.

Returning to Flowchart 1, box 4B is the decision branch in which the additivity of the wavelengths is decided. If they are not additive, a NOHD should be calculated for each wavelength and the most restrictive NOHD (largest) chosen (boxes 5B, 6B).

Box 4C is the decision branch where the decision is made as to whether the MPEs are identical for all of the wavelengths. If so, the power in each wavelength can be added and treated as one wavelength to obtain an NOHD (boxes 4D, 6A).

If the effects of the wavelengths are additive (box 4B) but the MPEs are not identical (box 4C) then the contribution from each wavelength as a fraction of the MPE for that wavelength should be added. Assuming that there are $n$ wavelengths each with a power $P_i$ and an MPE of $MPE_i$, then the following calculation should be made:

$$\frac{P}{MPE} = \frac{P_1}{MPE_1} + \frac{P_2}{MPE_2} + \cdots + \frac{P_n}{MPE_n} \tag{20}$$

The NOHD can then be calculated using the appropriate equation in 9.2.

$$NOHD = \frac{1}{\phi}\left[\frac{4 \times k \times P}{\pi \times MPE}\right]^{0,5} - \frac{a}{\phi} \tag{21}$$

Note that if some wavelengths do not have the same MPE the sequence (boxes 4B, 4C, 5, 6A) should be used.

If required, the nominal skin hazard distance (NSHD) for CW laser products can be calculated using Flowchart 1, except Table 8 of IEC 60825-1 is used to obtain the skin MPEs. In a skin hazard zone appropriate skin protection will be required.

### 9.4 NOHD calculation for pulsed laser products

Except for the calculation of MPEs the calculation of NOHD for pulsed laser products follows a similar procedure to that for CW laser products. The MPE is determined from the most restrictive of three cases as described in 13.3 of IEC 60825-1. A procedure for calculating the NOHD for pulsed laser products with a constant amplitude and pulse repetition frequency (PRF) is described in Flowchart 2 of Annex A. The calculation of MPEs for a pulsed laser product is described in Flowchart 3 of Annex A.

Referring to Flowchart 3, box 1, the first calculation (see 13.3(a) of IEC 60825-1) refers to the MPE for a single pulse. It is evident that if a train of pulses is to be safe, each single pulse in the train must be safe. Thus $MPE_a$ is calculated from the consideration of a single pulse. If more than one pulse occurs in a time $T_i$ (see 13.3(c) of IEC 60825.1) the total radiant exposure within the time $T_i$ should be treated as one single pulse of duration $T_i$ (see definition of t on Flowchart 3).

The second calculation (see 13.3(b) of IEC 60825-1) refers to the average exposure over the exposure time (Flowchart 3, box 2). It is evident that if a series of pulses is to be safe, the total radiant exposure received during the exposure time should not be greater than the radiant exposure equivalent to the MPE as calculated for a CW laser in the same time period. In cases where the MPE for the full exposure time ($MPE_T$) is expressed in J·m$^{-2}$ the equivalent MPE per pulse ($MPE_b$) is determined by:

$$MPE_b = \frac{MPE_T}{PRF \times T} = \frac{MPE_T}{N} \qquad (22)$$

where

$PRF$ is the pulse repetition frequency expressed in pulses per second, and

$T$ is the exposure time or $T_2$ whichever is the lesser for 400 nm ≤ λ < 1 400 nm and $T$ is the exposure time or 10 s whichever is the lesser for λ ≤ 1 400 nm (see 13.3(c) of IEC 60825-1 and Note 2 of Flowchart 3).

Note that if the repetition rate is constant during the exposure time, $PRF \times T = N$, the number of pulses in the train. $MPE_b$ is the radiant exposure that would be allowed for each single pulse if this condition is to be met.

In cases where $MPE_T$ is in units of W·m$^{-2}$ the average MPE per pulse can be determined by dividing $MPE_T$ by the PRF (see Note 2 of Flowchart 3). The MPE in W·m$^{-2}$ divided by the PRF is equivalent to the number of J·m$^{-2}$ that would be allowable for each pulse of a repetitively pulsed laser operating at that constant PRF.

For wavelengths between 400 nm and 10$^6$ nm in cases where the thermal limits apply, the third calculation (see 13.3(c) of IEC 60825-1 and box 4 of Flowchart 3) reduces $MPE_a$ to take account of the cumulative damage which can occur when tissue is exposed to a series of laser pulses. Research has shown that, in cases where the thermal limits apply, the potential for damage increases with each pulse, and as a result, the MPE should be reduced to take account of this effect. Thus,

$$MPE_c = MPE_a \times C_5 \qquad (23)$$

where

$C_5$ is $N^{-1/4}$ (for thermal limits) and

$N$ is the number of pulses in the exposure (i.e. $N = PRF \times T$).

For wavelengths between 400 nm and 600 nm in cases where the photochemical MPE is the most restrictive, the third calculation of MPE (see 13.3(c) of IEC 60825-1) is not required.

For wavelengths between 400 nm and 10$^6$ nm (box 3) in cases where the thermal limits apply, the most restrictive (i.e. the smallest) MPE from $MPE_a$, $MPE_b$, and $MPE_c$ (box 5B) becomes $MPE_p$. For other wavelengths and in cases where the photochemical limits are the most restrictive, the most restrictive of $MPE_a$ and $MPE_b$ is chosen for $MPE_p$ (box 5A).

Note that for repetitively pulsed laser products with PRFs of less than 1 kHz, where thermal limits apply, it is very likely that $MPE_c$ will be the most restrictive.

It remains to check whether the value $MPE_p$ is more restrictive in peak power than would be the power allowable for a CW laser. This is done in boxes 6 to 8. $E_{max.}$ is determined. If $E_{max.}$ is greater than or equal to the $MPE_T$ then the MPE for the problem is the one calculated as $MPE_p$ (box 8A). In cases where $H_{max.}$ is less than that allowable for a CW laser (box 8B) then $MPE_T$ may be used. (See the last paragraph of 13.3, IEC 60825-1)

The NSHD (nominal skin hazard distance) for pulsed laser products can be calculated using Flowchart 2 except where Table 8 of IEC 60825-1 is used to obtain the skin MPEs.

### 9.5 NOHD for magnifying optics

Magnifying optical instruments are designed to magnify the image on the retina using lenses, mirrors or a combination of these. There are two conditions to investigate. The first is the magnifying glass and the second is the telescope, including binoculars and microscopes. As the boundary condition, the worst case (biggest) aperture of the human eye is taken as 7 mm. For assessing the skin risk in the relevant wavelength range the diameter of the reference aperture is 3,5 mm. For a risk assessment, the availability of optical instruments for the normal user must be taken into account.

A common magnifier glass with a high magnification is a 8× or 10× lens. When one is used the shortest focal length of such a lens is about 28 mm, assuming that the lens is used directly in front of the eye and the standard accommodation to 250 mm is used. There are lenses available with shorter focal lengths such as microscope lenses. These are not intended to be used as a magnifier glass. With decreasing focal length, the diameter does not increase and is mostly smaller than 7 mm. The worst case situation is the source positioned in the focal plane, and the eye directly behind the magnifier lens. For wavelengths where the cornea is highly absorbing (outside the optical hazard region) another condition might be critical, when the radiation is focused on the plane of the cornea. However, that is not a condition of normal use.

Common binoculars are 8×30 or 7×50, sometimes 10×60 or 11×56. The first value is the magnification while the second is the diameter of the entrance pupil in millimetres. The diameter of the exit pupil is the diameter of the entrance pupil divided by the magnification. The worst case condition regarding the collimated power fed to the entrance of the pupil of the eye is when both pupils have the same diameter of 7 mm. In the IEC 60825-1 standard, 50 mm is taken as the reference for magnifying optics. A 50 mm aperture with a magnification of 7 is optimally adapted to the human eye with an exit diameter of 50/7 = 7,1 mm. A 10×60 binocular carries a higher risk because it can collect more power ($60^2/50^2$ = 1,44) into a 6 mm aperture. It should be kept in mind that for longer wavelengths the optics might still be transparent and a smaller aperture must be used for that wavelength range.

The diagram in Figure 7 indicates how magnifying optics such as telescopes and binoculars can concentrate radiation into the eye. For this reason the use of optical viewing aids may increase the danger from laser products. If they are being used, either they should be fitted with appropriate filters or the NOHD should be extended. A technique for calculating the concentrating effect of symmetric beams is described below.

The radiation entering the eye from a laser viewed through a pair of binoculars is increased by an optical gain factor $G$. The following rules are recommended.

a) For 400 nm ≤ λ ≤ 1 400 nm

Where the pupil is overfilled,

$$G = \tau \times M^2 \text{, or} \tag{24}$$

where the output beam is smaller than the pupil,

$$G = \frac{\tau \times {D_0}^2}{49} \tag{25}$$

whichever is the smaller,

where

$\tau$ is the transmission coefficient at the appropriate wavelength (=1 if unknown),

$M$ is the magnification, and

$D_o$ is the diameter of the objective lens in mm.

b) For 320 nm ≤ λ< 400 nm and 1 400 nm < λ ≤ 4500 nm

$$G = \tau \times M^2 \tag{26}$$

In this region the radiation is absorbed in the cornea.

c) For λ < 320 nm and λ > 4 500 nm

$$G = 1$$

In this region the radiation is unlikely to be transmitted through the viewing aid.

Binoculars are usually rated as 7×50 or similar. In this case the first number (7) is the magnification (*M*), and the second is the diameter of the objective lens in mm ($D_o$).

In cases where optical viewing aids are to be used, $NOHD_{\text{extended}}$ is calculated by:

$$NOHD_{\text{extended}} = \frac{1}{\phi}\left[\frac{4 \times k \times G \times P}{\pi \times MPE}\right]^{0,5} - \frac{a}{\phi} \tag{27}$$

In cases where $\frac{a}{\phi}$ can be ignored, the equation $NOHD_{\text{extended}} = \sqrt{G} \times NOHD$ is a conservative approximation.

The above example relates to binoculars or telescopes exposed to collimating laser beams. A similar hazard may exist if magnifying optics (such as jeweler's eye loupes) are used to view highly divergent radiation sources.

Viewing with the unaided eye

Viewing with magnifying optical instruments

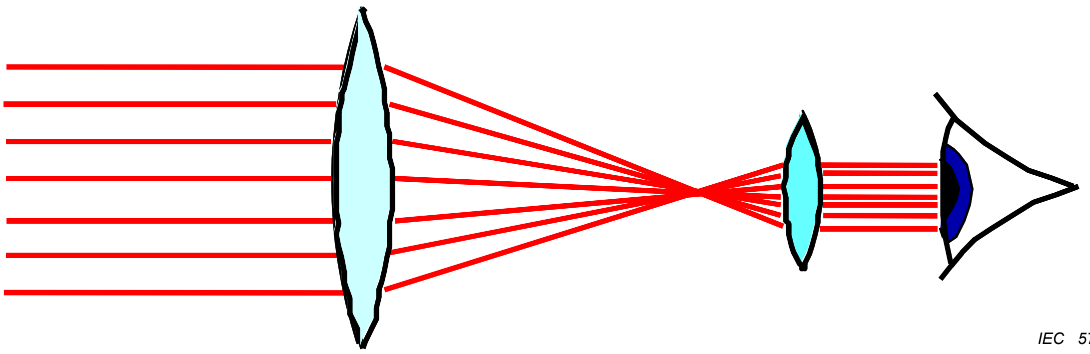



**Figure 7 – The effect of viewing a collimated beam with magnifying optics**

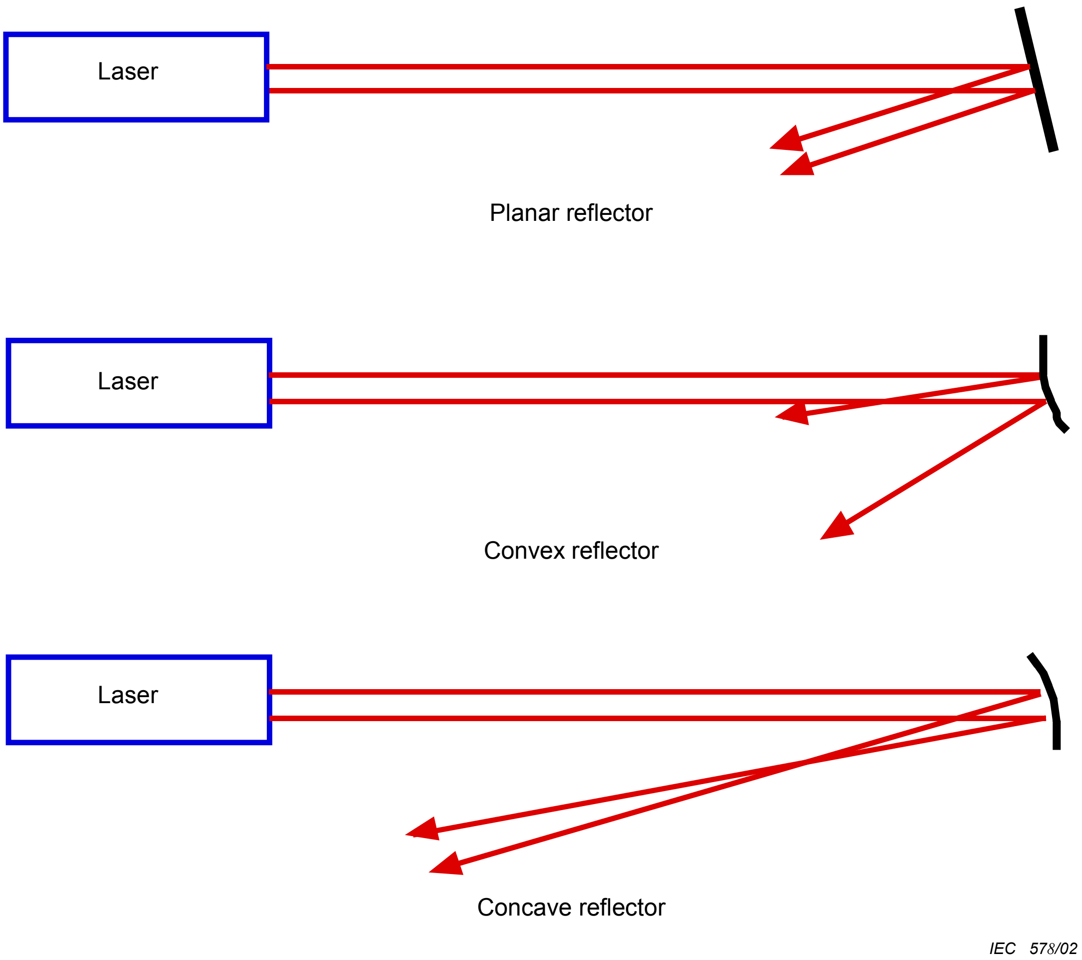



**Figure 8 – Types of specular reflections of collimated beams**

The above example relates to binoculars or telescopes exposed to collimated laser beams. A similar hazard may exist if magnifying optics (such as jeweler's eye loupes) are used to view highly divergent radiation sources.

## 9.6 Specular reflections

Specular reflections occur when radiation is reflected off smooth surfaces such as the surface of water, mirrors and glass. When specular reflections occur the reflected radiation retains the spatial information of the source. Figure 8 shows different types of specular reflections.

In the case of convex specular reflections, a ray diagram can be used to determine the divergence of the beam if sufficient information is known about the geometry of the reflector. A concave specular reflector may concentrate the beam and increase the irradiance or radiant exposure.

To determine if a specular reflection is dangerous, it is necessary to determine the fraction of the incident beam which is reflected. This is called the reflection coefficient $\rho$. For specular reflecting surfaces, $\rho$ is a function of the polarization of the beam and the angle of incidence as shown for illustrative purposes in Figure 9.

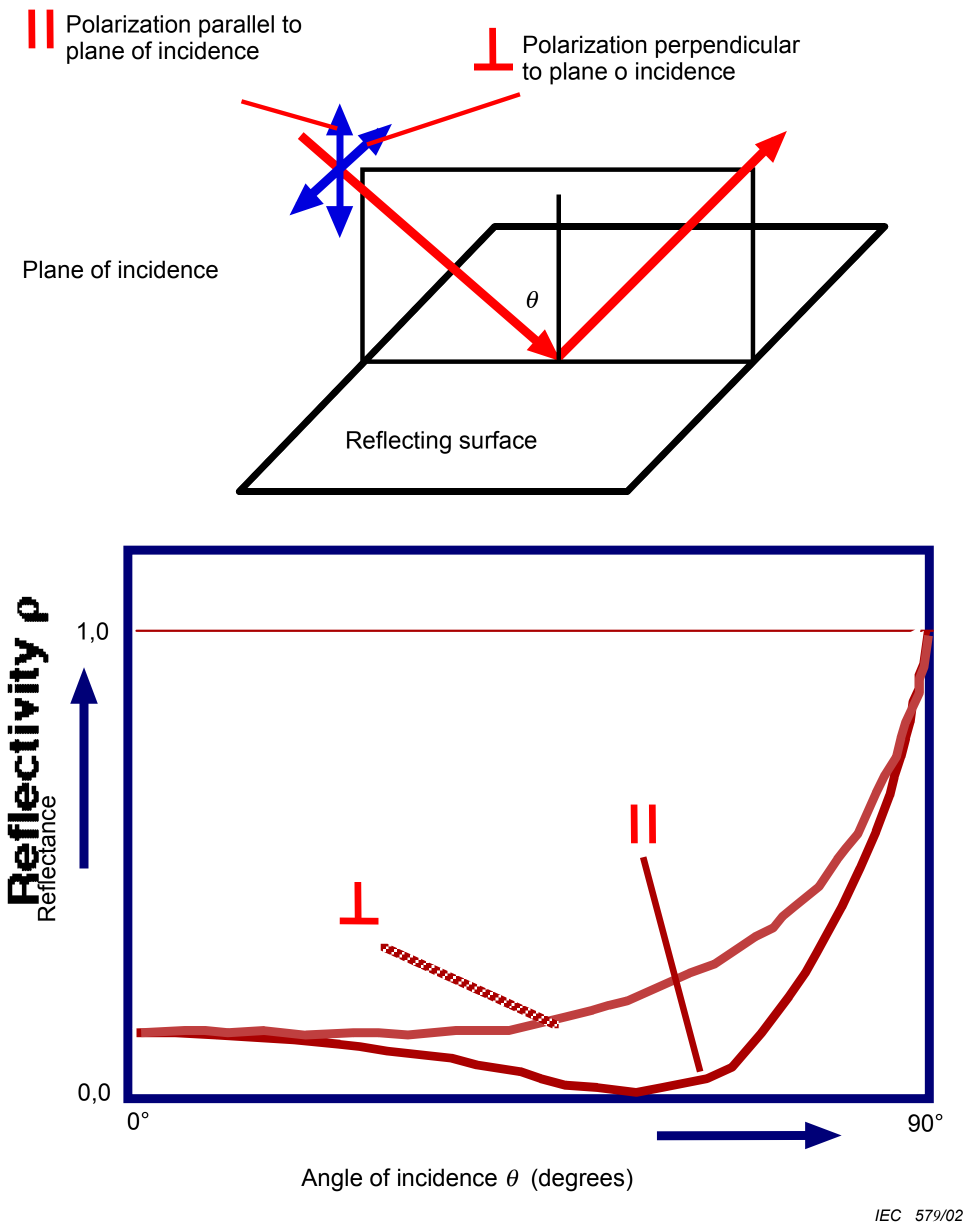



**Figure 9 – Specular reflections from the surface of transparent materials**

For plane specular surfaces, the calculations are performed in a similar manner to intrabeam viewing, as follows.

$$NOHD_{\text{reflection}} = \frac{1}{\phi}\left[\frac{4 \times k \times \rho \times P}{\pi \times MPE}\right]^{0,5} - \frac{a}{\phi} - R_{\text{reflector}} \qquad (28)$$

Where $R_{\text{reflector}}$ is the distance between the laser and the reflector. If $NOHD_{\text{reflection}}$ is negative, then viewing of the reflection is safe. If it is positive it represents the minimum distance from the reflector to the viewer at which viewing is safe.

If the NOHD has been calculated, and $\frac{a}{\phi}$ can be ignored, $NOHD_{\text{reflection}}$ can be conservatively approximated by:

$$NOHD_{\text{reflection}} \approx \rho^{0,5} \times NOHD - R_{\text{reflector}} \quad (29)$$

NOTE Reflectors which are diffuse for visible radiation may be specular for longer wavelengths and higher angles of incidence. Also, wet diffusers or ones subject to high levels of radiation may become specular.

### 9.7 Atmospheric attenuation

In circumstances where the NOHD is of the order of kilometres, it could be desirable to correct the NOHD for the attenuation in the beam caused by the scattering of the atmosphere. The radiant power (or energy) in the beam is reduced as follows:

$$P(r) = P_{\text{o}}\, e^{-\mu r} \quad (30)$$

or

$$Q(r) = Q_{\text{o}}\, e^{-\mu r} \quad (31)$$

where

$P(r)$ ($Q(r)$) is the power (radiant energy) in the beam at some distance $r$ from the laser,

$P_{\text{o}}$ ($Q_{\text{o}}$) is the power (radiant energy) at the laser; and

$\mu$ is the attenuation coefficient.

The attenuation coefficient for various atmospheric conditions can be obtained from the procedure set out in Annex A.5 of IEC 60825-1.

## 10 Extended source viewing

### 10.1 General

Extended sources can include both diffuse reflections and laser arrays producing beams where the apparent source subtends an angle greater than $\alpha_{\text{min}}$.

For the safe use of high powered laser products it is necessary to terminate the beam at a beamstop. Many common materials (provided that they are not ignited by the beam) form diffuse reflections. That is, the radiation is re-radiated in all directions from each point. A truly diffuse reflection is called a `Lambertian Reflection', and is discussed in 10.2. Many reflectors are somewhere in between diffuse and specular and care should be exercised. Also, a reflector which is diffuse at one wavelength, could be specular at a longer wavelength. In particular, surfaces which appear diffuse to visible radiation may be specular to infrared radiation. If in doubt, a specular reflection calculation is the most conservative.

The following considerations only apply to the wavelength range 400 nm to 1400 nm. However Flowchart 4 of Annex A can also be used for extended sources and diffuse reflections of other wavelengths.

### 10.2 Extended sources

In the following discussion diffuse reflections are considered as a special case of an extended source. Viewing distances are assumed to be 100 mm or greater.

Figure 4 shows that the size of the image of a diffuse reflection on the retina is determined by the angular subtense $\alpha$. The breakpoint between ‘point source viewing' and ‘extended source viewing' is determined by the minimum angle $\alpha_{\text{min}}$. $\alpha_{\text{min}}$ is the angle that the apparent source can subtend at the observer and still be considered as an ‘extended source'. Figure 10 shows the general conditions for the extended source viewing of a diffuse reflection.

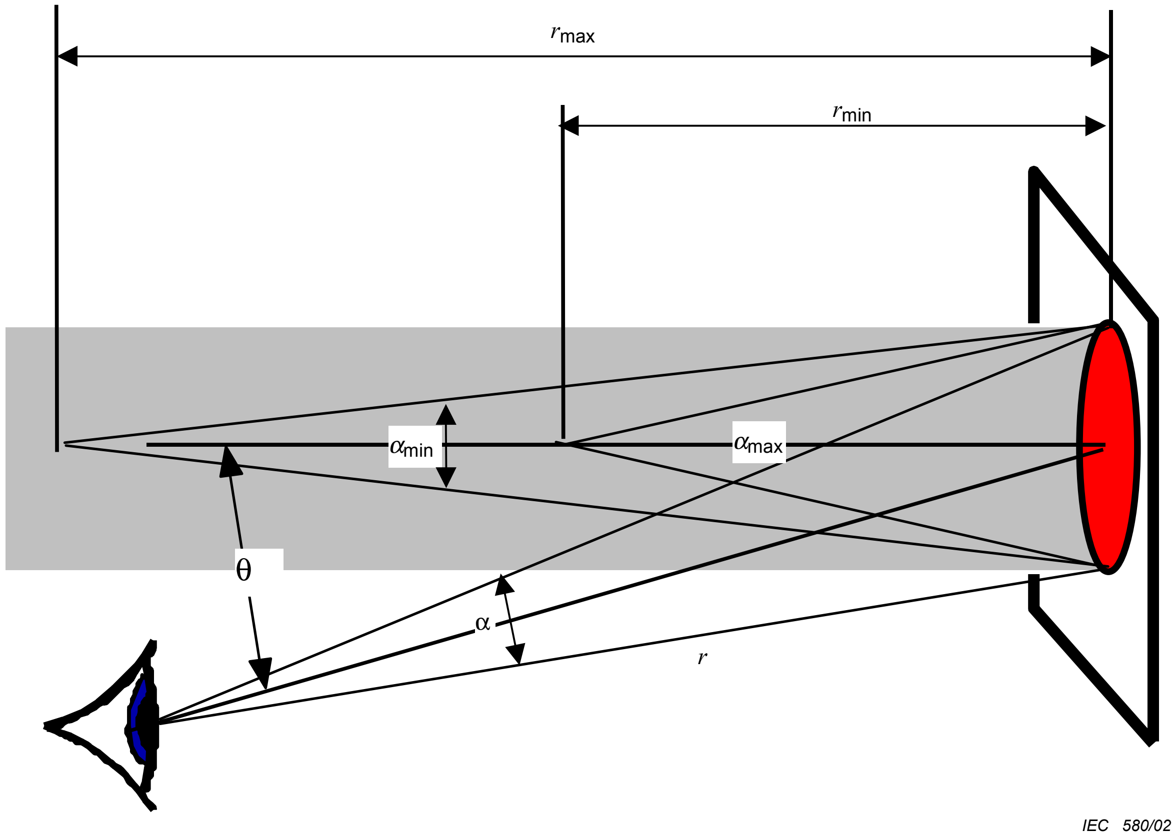



**Figure 10 – The conditions for extended source viewing**

All viewing of collimated beams, or diffuse sources for which the angular subtense is less than $\alpha_{min}$ are considered to be 'intrabeam viewing' or 'point source viewing'. The two terms are synonymous for the purposes of the standard.

As shown in Figure 10, for a spot diameter of a certain size, $\alpha_{min}$ is associated with a range $r_{max}$ beyond which point source viewing conditions exist. Another break point in the calculations occurs where the subtended angle is equal to $\alpha_{max}$ corresponding to a range of $r_{min}$. For viewing distances less than $r_{min}$ the image on the retina is large (greater than 1,7 mm) and the irradiance on the retina is constant as described below. Under these conditions the MPE depends solely on the irradiance (W·m$^2$) or radiant exposure (J·m$^2$) at the diffuser. Between $r_{min}$ and $r_{max}$ is a transition zone between very large retinal image conditions and the point source viewing conditions.

First consider the case where $r < r_{min,}$ and the image on the retina is very large.

Consider the situation shown in Figure 11.

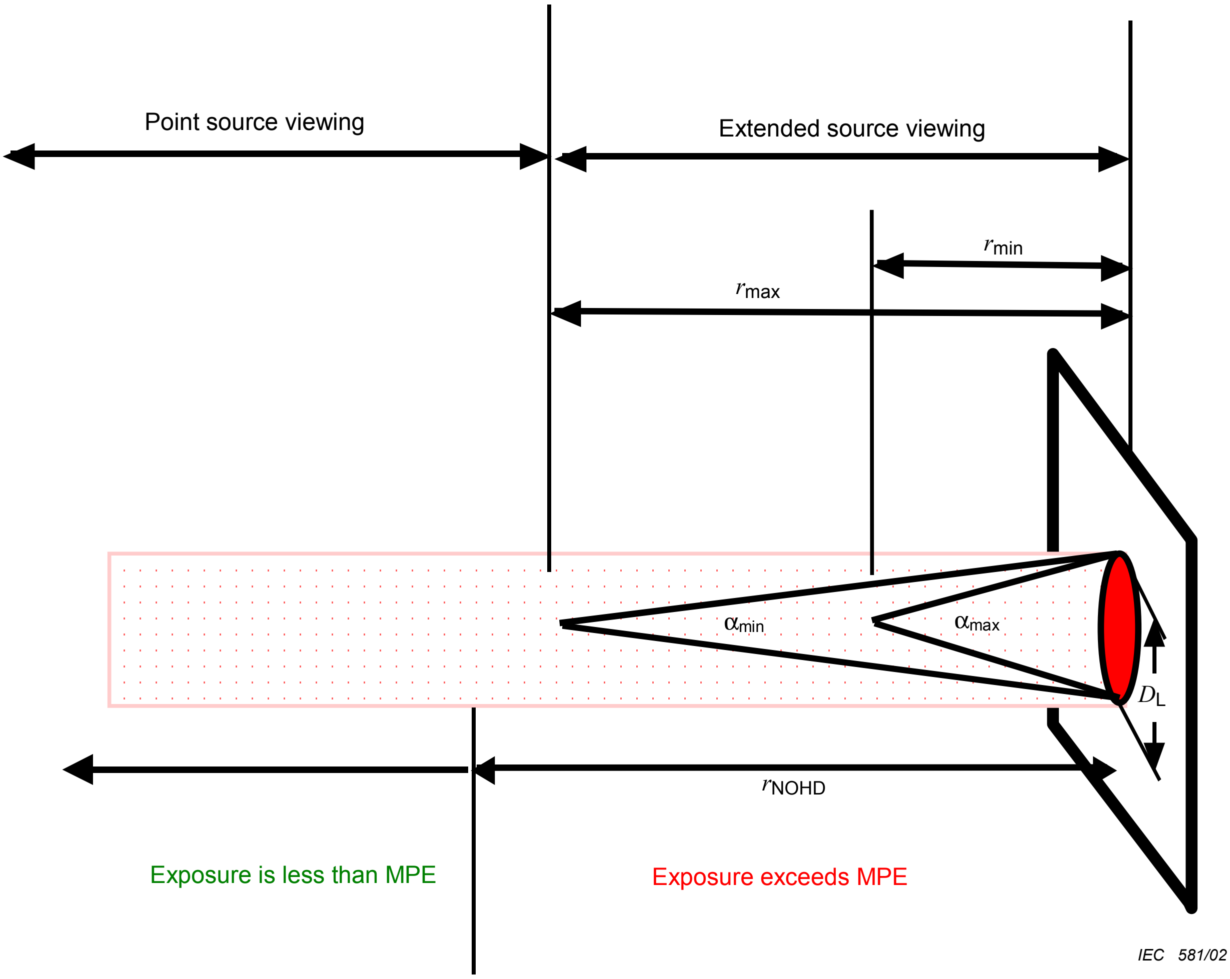



**Figure 11 – Conditions for viewing a diffuse reflection**

From Figure 4 it is evident that, for extended source viewing, $r < r_{min.}$

$$\frac{d_i}{F} = \frac{D_L}{r} \tag{32}$$

or

$$d_i \propto \frac{1}{r} \tag{33}$$

where

$d_i$ is the size of the image on the retina,

$F$ is the focal length of an eye (assumed to be 17 mm),

$D_L$ is the size of the object being viewed (Figure 11), and

$r$ is the distance from the diffuse reflection to the eye.

The area of the image ($A_i$) on the retina can be written as

$$A_i \propto {d_i}^2 \propto \frac{1}{r^2} \tag{34}$$

On the other hand the power entering the eye ($P_e$) decreases as the observer moves away from the reflector as follows:

$$P_e \propto \frac{1}{r^2} \quad (35)$$

Therefore the irradiance at the retina $E_{retina}$ becomes

$$E_{retina} = \frac{P_e}{A_i} \propto \frac{\frac{1}{r^2}}{\frac{1}{r^2}} \quad (36)$$

This shows that, $E_{retina}$ is independent of $r$ in the region $r < r_{min}$. The MPE is related to the irradiance at the retina. If a person moves toward the reflection from $r_{min}$, the increase in image size is exactly matched by the increase in radiant power entering the eye and the irradiance at the retina does not change.

Thus, since for $\alpha > \alpha_{max}$ the MPE does not depend on the retinal image size if the exposure is less than the MPE at one point in the region $r < r_{min.}$, it is safe at all points in that region. If the MPE is exceeded at one point in that region, it is exceeded at all points in that region.

If viewing is unsafe in the region $r < r_{min.}$ it may be necessary to calculate the distance at which viewing the diffuse reflection is safe ($r_{NOHD}$). See Figure 11. The irradiance ($E$) from a Lambertian reflector or Lambertian source at a distance $r$ is given by Lambert's equation:

$$E = \rho \frac{P_o \times \cos\theta}{\pi \times r^2} \quad (37)$$

where

$P_o$ is the total power being produced by the laser,

$\theta$ is described in Figure 10,

$r$ is the distance from the diffuse reflection to the eye, and

$\rho$ is the reflectivity.

This equation gives the irradiance at an observer a distance $r$ from a diffuse reflector. It is not the irradiance at the reflector.

If we consider the case of a CW laser, the value of $r_{NOHD}$ can be determined by setting $E$ equal to the MPE (in W·m$^{-2}$) and $r$ equal to $r_{NOHD}$.

$$MPE = \rho \frac{P_o \cos\theta}{\pi \times r_{NOHD}^2} \quad (38)$$

for $r \geq r_{min.}$

After some algebraic manipulation we obtain

$$r_{NOHD} = \left[ \rho \frac{P_o \cos\theta}{\pi \times MPE} \right]^{0,5} \quad (39)$$

for $r \geq r_{min.}$

In the case of a pulsed laser with pulse energy $Q$ the radiant exposure is given by :

$$H = \frac{\rho\, Q_0 \cos\theta}{\pi \times r^2} \tag{40}$$

for $r \geq r_{\min}$

The equivalent equation for a pulsed laser for which the MPE is in J·m$^{-2}$ is

$$r_{\text{NOHD}} = \left[ \rho \frac{Q_0 \cos\theta}{\pi \times MPE} \right]^{0,5} \tag{41}$$

for $r \geq r_{\min}$

In cases where the reflectivity $\rho$ is unknown it should be taken as 1.

In the transitional zone between $r_{\min}$ and $r_{\max}$ the MPE is corrected by correction factor $C_6$ which gives a smooth transition between the two regions $r < r_{\min}$ and $r > r_{\max}$ .

The value of $C_6$ is given by :

$C_6 = \dfrac{\alpha_{\max}}{\alpha_{\min}}$ for $r < r_{\min}$ (i.e. $\alpha > \alpha_{\max}$ ),

$C_6 = 1{,}0$ for all $r \geq r_{\max}$ (i.e. $\alpha \leq \alpha_{\min}$ see Figure 10) ,and

$C_6 = \dfrac{\alpha}{\alpha_{\min}}$ for $r_{\min} \leq r < r_{\max}$ (i.e. $\alpha_{\min} < \alpha \leq \alpha_{\max}$ ) (42)

In the range $r_{\min} \leq r < r_{\max}$ :

$$MPE = MPE_{\text{pt source}}\, C_6 = MPE_{\text{pt source}} \frac{\alpha}{\alpha_{\min}} = MPE_{\text{pt source}} \frac{r_{\max}}{D_L} \frac{D_L}{r} = MPE_{\text{pt source}} \frac{r_{\max}}{r} \tag{43}$$

where

$D_L$ is the diameter of the diffuse reflection (see Figure 11), and

$MPE_{\text{pt source}}$ is the MPE calculated for intrabeam viewing ($r > r_{\max}$).

Therefore in this range, setting $\cos\theta = \rho = 1{,}0$ (the worst case), we can deduce from equation 38:

$$MPE = MPE_{\text{pt source}} \frac{r_{\max}}{r_{\text{NOHD}}} = \frac{P_o}{\pi \times r_{\text{NOHD}}^2} \tag{44}$$

or, after rearrangement

$$r_{\text{NOHD}} = \frac{P_o}{\pi \times MPE_{\text{pt source}} \times r_{\max}} \tag{45}$$

### 10.3 Calculation of $r_{NOHD}$

The distance $r_{NOHD}$ is the minimum distance from a diffuse reflector or extended source at which viewing is safe. That is, viewing is unsafe for $r < r_{NOHD}$, but safe for viewing at greater ranges (i.e. $r \geq r_{NOHD}$).

One method of calculating $r_{NOHD}$ is now described. The procedure begins with checking to see if viewing is safe for $r < r_{min}$. If this region is safe, viewing must be safe everywhere. If it is unsafe, then $r_{NOHD}$ must be greater than $r_{min}$ and the calculation should be based on Lambert's equation.

The procedure is set out in Flowchart 4 of Annex A. In box 1 the basic parameters are calculated. In box 2 one of two separate calculation paths is selected depending on the units of the MPE. Both paths are identical except for differences in the equations relating to units.

Following the chart on the left hand side, the radiant exposure at the diffuser ($H_d$) is calculated. Following the Note in 13.5 of IEC 60825-1, calculate $L_{MPE}$ and the integrated radiance at the diffuser relating to the MPE (box 3A).

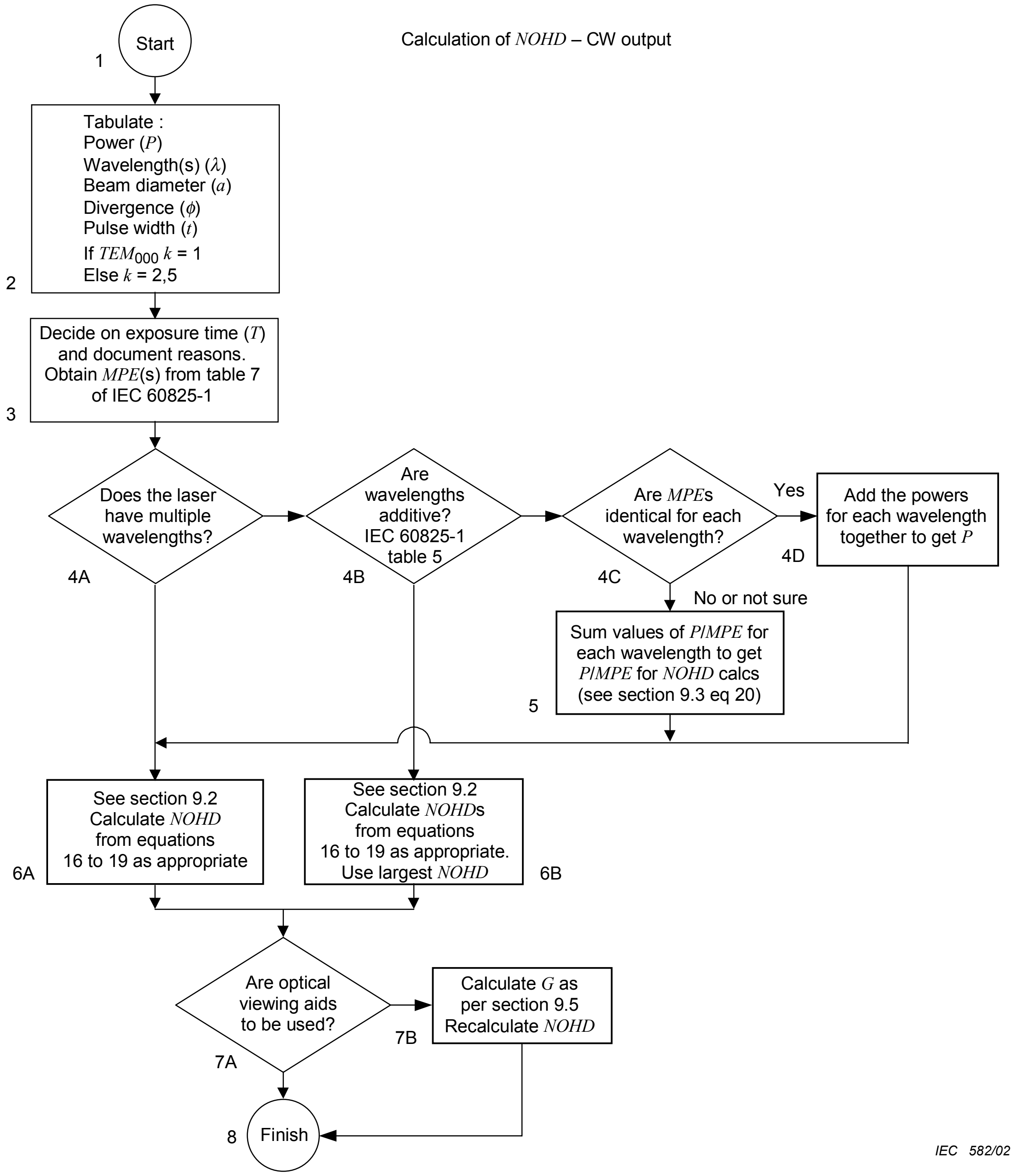
If the actual radiant exposure at the diffuser ($H_d$) is less than the radiant exposure relating to the MPE ($H_{MPE}$, box 4A) the viewing is safe for $r < r_{min}$ and is therefore safe everywhere (box 4B).

If viewing in the region $r < r_{min}$ is not safe, a temporary variable $r'$ is calculated (box 5a). $r'$ is equal to the minimum safe viewing distance if it is less than $r_{max}$ (boxes 6A and 6B). If $r'$ is greater than or equal to $r_{max}$ then $r_{NOHD}$ is calculated from the formula in box 7A.

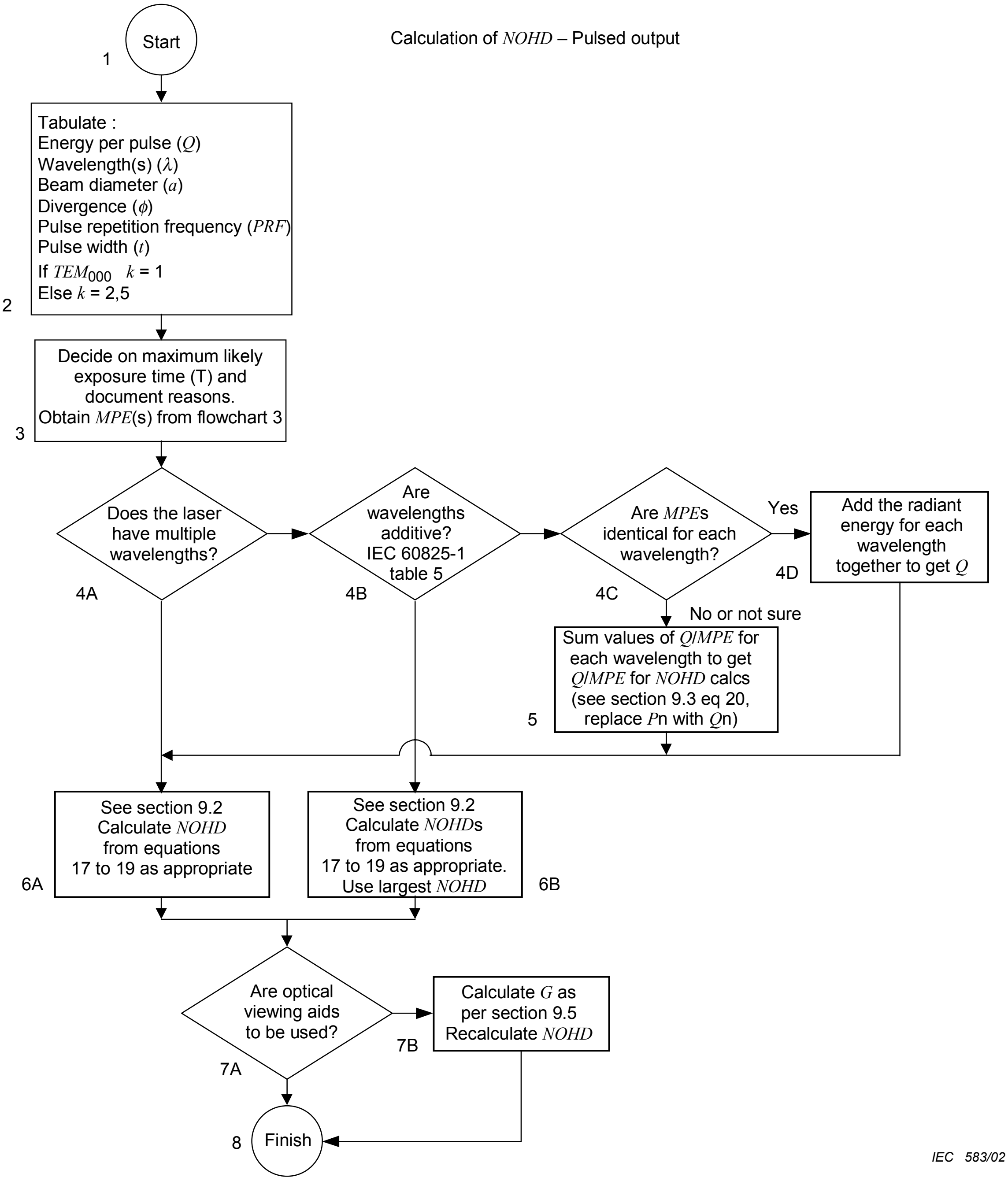
The right hand side of the flowchart follows the same logic for MPEs expressed in $W{\cdot}m^{-2}$.

# Annex A
(normative)

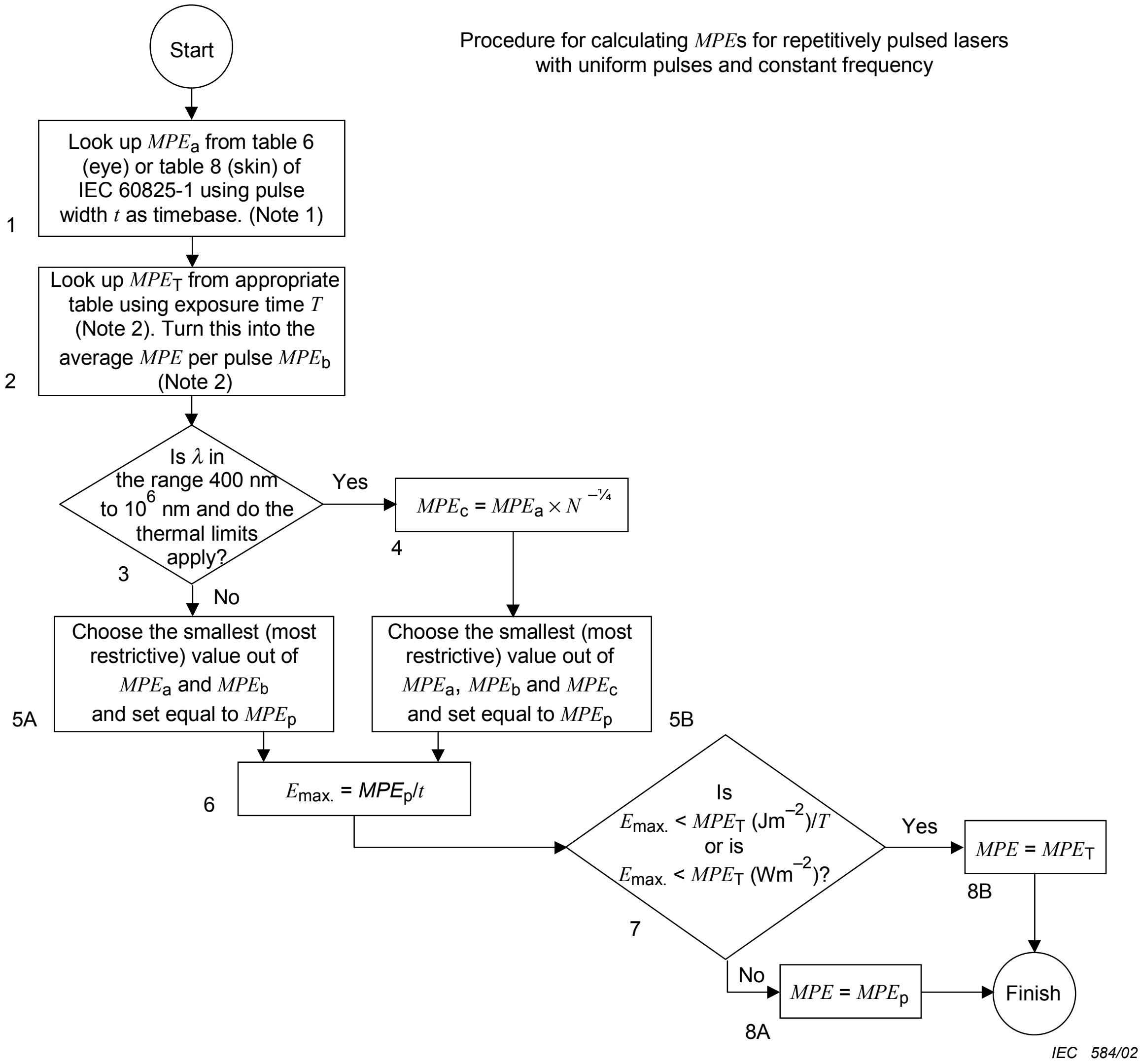
## Flowcharts




**Flowchart 1 – Calculation of NOHD for CW output**




**Flowchart 2 – Calculation of NOHD for pulsed output**




$t$ = pulse width, usually in ns or µs (if multiple pulses occur within a time $T_i$ then they should be treated as a single pulse of duration $T_i$, see 13.3 (c) of IEC 60825-1)

$T$ = exposure time usually in seconds

$N$ = number of pulses in exposure time $T$ (see 13.3 of IEC 60825-1)

NOTE 1 If $MPE_a$ is in W·m$^{-2}$ then change to J·m$^{-2}$ by multiplying by $t$.

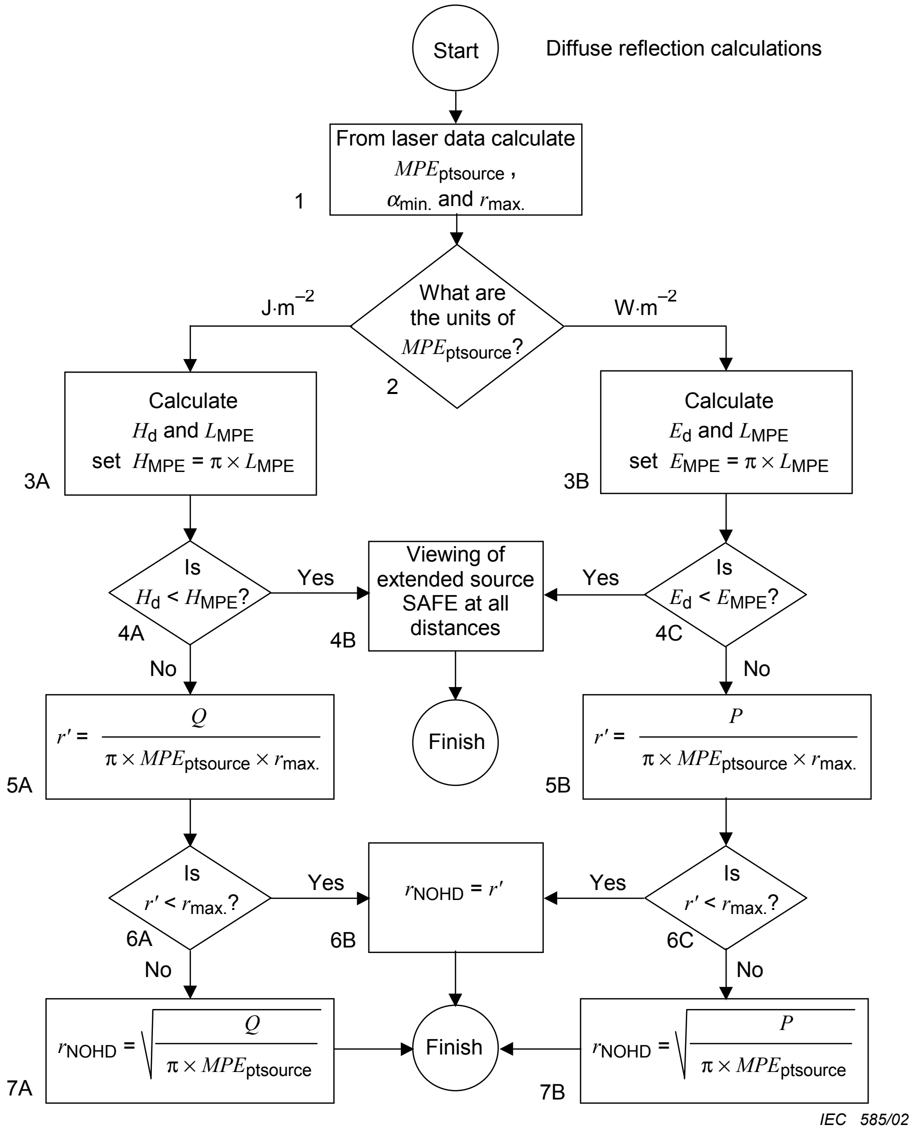
NOTE 2 If 400 nm ≤ $\lambda$ < 1 400 nm and $T > T_2$ then $T = T_2$ (see 13.3 (c) of IEC 60825-1).

If $\lambda$ < 1 400 nm and $T$ > 10 s then $T$ = 10 s.

If $MPE_T$ is in W·m$^{-2}$ then $MPE_b = MPE_T/PRF$ (in units of J·m$^{-2}$).

If $MPE_T$ is in J·m$^{-2}$ then $MPE_b = MPE_T/N$ (in units of J·m$^{-2}$).

**Flowchart 3 – Calculation of MPE for pulsed lasers**




NOTE 1 If $\lambda < 400$ nm or $\lambda > 1\,400$ nm then proceed directly to box 7A for $MPE$s in units of J·m$^{-2}$ or to box 7B for $MPE$s in units of W·m$^{-2}$ to calculate $r_{NOHD}$.

NOTE 2 $\alpha_{min.}$ : minimum angular subtense

$r_{max.}$, $r_{min.}$ : see figure 12

$MPE_{ptsource}$ : $MPE$ at $r > r_{max.}$

$H_d$ : radiant exposure at diffuser

$E_d$ : irradiance at diffuser

$L_{MPE}$ : (see 13.5 of IEC 60825-1) the $MPE$ expressed as an integrated radiance or radiance at diffuser

$r_{NOHD}$ : safe distance from diffuser

$r'$ : temporary variable

**Flowchart 4 – Hazard calculation for diffuse reflection**

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