



BS 7192:1989

UDC [621.375.826 + 681.7.069.24] : 614.875

© British Standards Institution. No part of this publication may be photocopied or otherwise reproduced without the prior permission in writing of BSI

---

British Standard Specification for  
**Radiation safety of laser products**

(Implementation of CENELEC HD 482 S1)

---

British Standards Institution

**AVA** Documents  
Document Sharing Hub

## Contents

|                                                                                                                                                        | Page       |                                                                                                                                                             | Page |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Foreword                                                                                                                                               | 1          | DI. Summary of the physical quantities used in this standard                                                                                                | 71   |
| Committees responsible                                                                                                                                 | Back cover | DII. Summary of manufacturer's requirements                                                                                                                 | 72   |
| <b>Specification</b>                                                                                                                                   |            | DIII. Summary of user precautions                                                                                                                           | 73   |
| <b>Section one. General</b>                                                                                                                            |            | <b>Figures</b>                                                                                                                                              |      |
| 1. Scope                                                                                                                                               | 2          | 1. Correction factor $C_1$ for emission durations from $10^{-9}$ s to 10 s                                                                                  | 42   |
| 2. Object                                                                                                                                              | 2          | 2. Correction factor $T_1$ for $\lambda = 302.5$ nm to 315 nm                                                                                               | 42   |
| 3. Definitions                                                                                                                                         | 3          | 3. Correction factor $C_2$ for $\lambda = 302.5$ nm to 315 nm                                                                                               | 42   |
| <b>Section two. Manufacturing requirements</b>                                                                                                         |            | 4. Correction factor $T_2$ for $\lambda = 550$ nm to 700 nm                                                                                                 | 43   |
| 4. Engineering specifications                                                                                                                          | 10         | 5. Correction factor $C_3$ for $\lambda = 550$ nm to 700 nm                                                                                                 | 43   |
| 5. Labelling                                                                                                                                           | 13         | 6. Correction factor $C_4$ for $\lambda = 700$ nm to 1 050 nm                                                                                               | 43   |
| 6. Other informational requirements                                                                                                                    | 15         | 7. Correction factor $C_5$ for pulse repetition frequencies $N$ from 1 to 1 000 $s^{-1}$                                                                    | 44   |
| 7. Additional requirements for specific laser products                                                                                                 | 16         | 8. Limiting angular subtense (apparent visual angle) $\alpha_{min}$ , for $\lambda = 400$ nm to 1 400 nm at exposure durations from $10^{-9}$ s to $10^3$ s | 44   |
| 8. Tests                                                                                                                                               | 17         | 9a. MPE for direct ocular exposure to ultra-violet radiation at selected emission durations from $10^{-9}$ s to $10^3$ s                                    | 45   |
| 9. Classification                                                                                                                                      | 18         | 9b. MPE for direct ocular exposure to ultra-violet radiation for exposure durations from $10^{-9}$ s to $10^3$ s at selected wavelengths                    | 45   |
| <b>Section three. User's guide</b>                                                                                                                     |            | 10a. MPE for direct ocular exposure to visible and infra-red radiation ( $\lambda = 400$ nm to $10^6$ nm) intrabeam viewing for single pulses or exposures  | 46   |
| 10. Safety precautions                                                                                                                                 | 27         | 10b. MPE for direct ocular exposure for exposure durations greater than 1 s for selected wavelengths between 400 nm and 1 400 nm                            | 47   |
| 11. Hazards incidental to laser operation                                                                                                              | 30         | 11a. MPE for direct ocular exposure ( $\lambda = 400$ nm to 700 nm and 1 050 nm to 1 400 nm) from extended sources for single pulses or exposures           | 48   |
| 12. Procedures for hazard control                                                                                                                      | 31         | 11b. MPE for direct ocular exposure from extended sources as a function of exposure duration at selected wavelengths between 400 nm and 1 400 nm            | 49   |
| 13. Maximum permissible exposures                                                                                                                      | 35         | 12a. AEL for Class 1 ultra-violet laser products for selected emission durations from $10^{-9}$ s to $10^3$ s                                               | 50   |
| <b>Appendices</b>                                                                                                                                      |            | 12b. AEL for Class 1 ultra-violet laser products for emission durations from $10^{-9}$ s to $10^3$ s at selected wavelengths                                | 50   |
| A. Examples of calculations                                                                                                                            | 54         | 13. AEL for Class 1 visible and infra-red laser products                                                                                                    | 51   |
| B. Medical considerations                                                                                                                              | 64         | 14. Warning label—Hazard symbol                                                                                                                             | 52   |
| C. Bibliography                                                                                                                                        | 70         | 15. Explanatory label                                                                                                                                       | 53   |
| D. Summary tables                                                                                                                                      | 71         | B1. Anatomy of the eye                                                                                                                                      | 68   |
| X. Original text of IEC Publication 825: 1984, prior to modification by HD 482 S1 together with the justification for the modification given in the HD | 74         | B2. Diagram of laser-induced damage in biological systems                                                                                                   | 60   |
| <b>Tables</b>                                                                                                                                          |            |                                                                                                                                                             |      |
| I. Accessible emission limits for Class 1 laser products                                                                                               | 22         |                                                                                                                                                             |      |
| II. Accessible emission limits for Class 2 laser products                                                                                              | 23         |                                                                                                                                                             |      |
| III. Accessible emission limits for Class 3A laser products                                                                                            | 24         |                                                                                                                                                             |      |
| IV. Accessible emission limits for Class 3B laser products                                                                                             | 25         |                                                                                                                                                             |      |
| V. Additivity of effects on eye (o) and skin (s) of radiation of different spectral regions                                                            | 35         |                                                                                                                                                             |      |
| VI. Maximum permissible exposure (MPE) at the cornea for direct ocular exposure to laser radiation (intrabeam viewing)                                 | 38         |                                                                                                                                                             |      |
| VII. Maximum permissible exposure (MPE) at the cornea for viewing an extended source laser or a laser beam by diffuse reflection                       | 39         |                                                                                                                                                             |      |
| VIII. Maximum permissible exposure (MPE) of skin to laser radiation                                                                                    | 40         |                                                                                                                                                             |      |
| BI. Summary of pathological effects associated with excessive exposure to light                                                                        | 66         |                                                                                                                                                             |      |

## Foreword

This British Standard has been prepared under the direction of the Electronic Equipment Standards Policy Committee. It implements CENELEC\* Harmonization Document HD 482 S1, which is in turn based on IEC Publication 825 : 1984. This British Standard supersedes BS 4803 : Parts 1 to 3 which are withdrawn in accordance with CENELEC Internal Regulations. The proposed common modifications were circulated in a draft for public comment reference 87/30839 DC and subsequently the United Kingdom supported the proposal. It was initially intended to amend BS 4803 but the decision was subsequently taken to issue this standard and withdraw BS 4803.

The CENELEC modifications have been included in the text in the appropriate positions and are indicated by a single side line in the margin of the page. References are included to items of the original IEC text which are given in appendix X together with the justification in the CENELEC Harmonization Document for the modifications.

The CENELEC Harmonization Document was approved by the CENELEC Technical Board on 1 March 1988.

## Cross-references

| International Standard | Corresponding British Standard                                                                                                      |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| ISO 1000 : 1981        | BS 5555 : 1981 Specification for SI units and recommendations for the use of their multiples and certain other units<br>(Identical) |

The Technical Committee has reviewed the provisions of IEC 27-1 : 1981 to which reference is made in Table D1 and has decided they are acceptable for use in conjunction with this standard. Definitions to IEC Publication 50(45) : International Electrotechnical Vocabulary (IEV), Chapter 45, referred to in clause 3, have been used except where indicated.

## Additional information

The object clause of this standard should be read as the scope.

Figures 9b, 12a and 12b have been modified by CENELEC to cover a range between 180 mm and 1 mm. Figures 14 and 15 have been modified by CENELEC to simplify the label edges.

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

\*CENELEC = European Committee for Electrotechnical Standardization.

---

British Standard Specification for

# Radiation safety of laser products

---

## SECTION ONE — GENERAL

### 1. Scope

This standard is applicable to radiation from laser products. The requirements for electrical safety are detailed in another IEC standard under consideration. For convenience this standard has been divided into three separate sections: Section One (General) and the appendices (of interest to all concerned); Section Two (Manufacturing requirements); and Section Three (User's Guide)<sup>1)</sup>.

A laser product may consist of a single laser with or without a separate power supply or may incorporate one or more lasers in a complex optical, electrical, or mechanical system. Typically, laser products are used for demonstration of physical and optical phenomenon; material processing; data reading and storage; transmission and display of information; etc. Such systems have found use in industry, business, entertainment, research, education and medicine. However, laser products which are sold to other manufacturers for use as components of any system for subsequent sale are not subject to this standard, since the final product will itself be subject to this standard.

The MPE (maximum permissible exposure) values of this standard were developed for laser radiation and do not apply to collateral radiation. The MPE values shall not be applicable to patient exposure to laser radiation for the purpose of medical treatment.

*Note.* — Appendices A to D have been included for purposes of general guidance and to illustrate many typical cases. However, the appendices must not be regarded as definitive or exhaustive and reference should always be made to the appropriate clause(s) in Sections One to Three.

### 2. Object

- 2.1 To protect persons from laser radiation in the wavelength range 180 nm to 1 mm<sup>2)</sup> by indicating safe working levels of laser radiation and by introducing a system of classification of lasers and laser products according to their degree of hazard.

NOTE. For information see X.1.

- 2.2 To lay down requirements for both user and manufacturer to establish procedures and supply information so that proper precautions can be adopted.

<sup>1)</sup> Some countries have requirements which differ from this standard. Therefore, contact the appropriate national agency for these requirements.

<sup>2)</sup> In this standard, the wavelength range  $\lambda_1$  to  $\lambda_2$  means  $\lambda_1 \leq \lambda < \lambda_2$  (e.g. 200 nm to 1 mm means  $200 \text{ nm} \leq \lambda < 1 \text{ mm}$ ).

- 2.3 To ensure adequate warning to individuals of hazards associated with accessible radiation from laser products through signs, labels and instructions.
- 2.4 To reduce the possibility of injury by minimizing unnecessary accessible radiation and to give improved control of the laser radiation through protective features and provide safe usage of laser products by specifying user control measures.

### 3. Definitions\*

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

#### 3.1 Access panel

A part of the protective housing or enclosure which provides access to laser radiation when removed or displaced.

#### 3.2 Accessible emission limit (AEL)

The maximum accessible emission level permitted within a particular class.

#### 3.3 Administrative control

Safety measures of a non-engineering type such as: key supervision, safety training of personnel, warning notices, count-down procedures, and range safety controls.

#### 3.4 Alignment laser product

The laser product designed, manufactured, intended or promoted for one or more of the following uses:

- a) determining and delineating the form, extent or position of a point, body or area by taking angular measurements,
- b) positioning or adjusting parts in proper relation to one another,
- c) defining a plane, level, elevation or straight line.

#### 3.5 Alpha min. ( $\alpha_{\min}$ )

See *Limiting angular subtense*, Sub-clause 3.39.

#### 3.6 Aperture, aperture stop

An aperture is any opening in the protective housing or other enclosure of a laser product through which laser radiation is emitted, thereby allowing human access to such radiation. An aperture stop is an opening serving to define the area over which radiation is measured.

#### 3.7 Apparent source

The real or virtual object that forms the smallest possible retinal image. Note that this definition is used to determine the location of the apparent origin of radiation in the wavelength range of 400 to 1400 nm, with the assumption of the apparent source being located in the eye's range of accommodation ( $\geq 100$  nm). In the limit of vanishing divergence, i.e. ideally collimated beam, the location of the apparent source goes to infinity.

NOTE. For information see X.2.

\* Arranged here for convenience in English alphabetical order. Departures from IEC Publication 50(45): International Electrotechnical Vocabulary (IEV), Chapter 45: Lighting, are intentional and are indicated.

### 3.8 *Beam divergence (Gaussian beam)*

For purposes of hazard assessment it is the plane angle of the mean cone of rays which in any cross-section encloses 63% of the total beam power (or energy). The diameter of the circle in any cross-section is the beam diameter at that point. The circle is the separation of points where the power (or energy) intensity falls to  $1/e$  of its central peak value. If the beam diameters are  $d_1$  and  $d_2$  metres at points  $x$  metres apart the beam divergence in radians is given by:

$$\frac{(d_2 - d_1)}{x}$$

### 3.9 *Beam expander*

A combination of optical elements which will increase the diameter of a laser beam.

### 3.10 *Class 1 laser product*

Any laser product which does not permit human access to laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission duration (see Sub-clause 9.2).

### 3.11 *Class 2 laser product*

Any laser product which:

- a) permits human access to laser radiation in excess of the accessible emission limits of Class 1, but not in excess of the accessible emission limits of Class 2 in the wavelength range from 400 nm to 700 nm;
- b) does not permit human access to laser radiation in excess of the accessible emission limits of Class 1 for any other wavelength (see Sub-clause 9.2).

### 3.12 *Class 3A and Class 3B laser product*

Any laser product which permits human access to laser radiation in excess of the accessible emission limits of Class 1 and Class 2 as applicable, but which does not permit human access to laser radiation in excess of the accessible emission limits of Classes 3A and 3B (respectively) for any emission duration and wavelength (see Sub-clause 9.2).

### 3.13 *Class 4 laser product*

Any laser product which permits human access to laser radiation in excess of the accessible emission limits of Class 3B (see Sub-clause 9.2).

### 3.14 *Collateral radiation*

NOTE. For information see X.3.

Any electromagnetic radiation, within the wavelength range between 200 nm and 1 mm, except laser radiation emitted by a laser product as a result of, or physically necessary for, the operation of a laser.

### 3.15 *Collimated beam*

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

### 3.16 *Continuous wave (CW)*

The output of a laser which is operated in a continuous rather than pulsed mode. In this standard, a laser operating with a continuous output for a period greater than 0.25 s is regarded as a CW laser.

### 3.17 *Demonstration laser product*

Any laser product designed, manufactured, intended or promoted for purposes of demonstration, entertainment, advertising, display or artistic composition. The term "demonstration laser product" does not apply to laser products which are designed and intended for other applications, although they may be used for demonstrating those applications.

### 3.18 *Diffuse reflection*

Change of the spatial distribution of a beam of radiation when it is scattered in many directions by a surface or medium. A perfect diffuser destroys all correlation between the directions of the incident and emergent radiation.

*Note.* — This definition is different from IEV 45-20-015.

### 3.19 *Embedded laser product*

In this standard a laser product which, because of engineering features limiting the accessible emissions, has been assigned a class number lower than the inherent capability of the laser incorporated.

### 3.20 *Emission duration*

The temporal duration of a pulse, of a train or series of pulses, or of continuous operation, during which human access to laser radiation could occur as a result of operation, maintenance or servicing of a laser product.

### 3.21 *Exposure time*

The duration of a pulse, or series, or train of pulses or of continuous emission of laser radiation incident upon the human body.

### 3.22 *Extended source viewing*

The viewing condition whereby the apparent source at a distance of 100 mm or more subtends an angle at the eye greater than the limiting angular subtense ( $\alpha$  min). Examples are viewing of diffuse reflections and of some laser diode arrays.

NOTE. For information see X.4.

### 3.23 *Fail safe*

The design consideration in which failure of a component does not increase the hazard. In the failure mode the system is rendered inoperative or non-hazardous.

### 3.24 *Fail safe safety interlock*

An interlock which in the failure mode does not defeat the purpose of the interlock, for example an interlock which is positively driven into the OFF position as soon as a hinged cover begins to open, or before a detachable cover is removed, and which is positively held in the OFF position until the hinged cover is closed or the detachable cover is locked in the closed position.

### 3.25 *Human access*

Capability for a part of the human body to meet hazardous laser radiation either as emitted from an aperture, by redirection from within a housing to the outside by the use of a reflector or optical guide or by insertion of part of the body through an enclosure port into the interior of the laser system; or by a failure mode of the laser equipment.

### 3.26 *Integrated radiance*

The integral of the radiance over a given exposure time expressed as radiant energy per unit area of a radiating surface per unit solid angle of emission (usually expressed in  $\text{J} \cdot \text{m}^{-2} \cdot \text{sr}^{-1}$ ).

### 3.27 *Intrabeam viewing*

All viewing conditions whereby the eye is exposed to laser radiation, other than extended source viewing.

### 3.28 *Irradiance*

At a point on a surface, the quotient of the radiant flux incident on an element of a surface containing the point by the area of that element.

Symbol:  $E_e$ ,  $E$  
$$E = \frac{d\Phi_e}{dA}$$

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

### 3.29 *Laser*

Any device which can be made to produce or amplify electromagnetic radiation in the wavelength range from 200 nm to 1 mm primarily by the process of controlled stimulated emission.

### 3.30 *Laser controlled area*

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

### 3.31 *Laser energy source*

Any device intended for use in conjunction with a laser to supply energy for the excitation of electrons, ions or molecules. General energy sources such as electrical supply mains or batteries shall not be considered to constitute laser energy sources.

### 3.32 *Laser hazard area*

See *Nominal ocular hazard area* (Sub-clause 3.46).

### 3.33 *Laser fibre optic transmission system*

A system consisting of one or more laser transmitters and associated fibre optic cable.

### 3.34 *Laser product*

Any product or assembly of components which constitutes, incorporates or is intended to incorporate a laser or laser system, and which is not sold to another manufacturer for use as a component (or replacement for such component) of an electronic product.

### 3.35 *Laser radiation*

All electromagnetic radiation emitted by a laser product between 200 nm and 1 mm which is produced as a result of controlled stimulated emission.

### 3.36 *Laser safety officer*

One who is knowledgeable in the evaluation and control of laser hazards and has responsibility for oversight of the control of laser hazards.

### 3.37 *Laser system*

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

### 3.38 *Levelling laser product*

See *Alignment laser product*, Sub-clause 3.4.

### 3.39 *Limiting angular subtense ( $\alpha_{\min}$ )*

The visual angle subtended by the apparent source (including diffuse reflections) at the eye of an observer which is used to differentiate between intrabeam and extended source viewing. See Figure 8, page 90 and Sub-clause 9.3c. This concept is discussed in Section B of Appendix A.

NOTE. For information see X.5.

### 3.40 *Limiting aperture*

The circular area over which irradiance and radiant exposure shall be averaged.

### 3.41 *Maintenance*

The performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser product, which are to be performed by the user for the purpose of assuring the intended performance of the product. It does not include operation or service.

### 3.42 *Maximum output*

The maximum radiant power, and where applicable the maximum radiant energy per pulse, of the total accessible laser radiation emitted in any direction by a laser product over the full range of operational capability at any time after manufacture.

### 3.43 *Maximum permissible exposure (MPE)*

That level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the radiation, the pulse duration or exposure time, the tissue at risk and, for visible and near infra-red radiation in the range 400 nm to 1400 nm, the size of the retinal image. Maximum Permissible Exposure levels are (in the existing state of knowledge) specified in Clause 13. Appendix A gives examples of the calculations of MPE levels.

### 3.44 *Medical laser product*

Any laser product designed, manufactured, intended or promoted for purposes of *in vivo* diagnostic, surgical, or therapeutic laser irradiation of any part of the human body.

3.45 *Mode-locking*

A regular mechanism or phenomenon, within the laser resonator, producing a train of very short pulses. While this may be a deliberate feature it may also occur spontaneously as “self-mode-locking”. The resulting peak powers may be significantly greater than the mean power.

3.46 *Nominal ocular hazard area (NOHA)*

The area within which the beam irradiance or radiant exposure exceeds the appropriate corneal maximum permissible exposure (MPE), including the possibility of accidental misdirection of the laser beam. If the NOHA includes the possibility of viewing through optical aids, this is termed the “extended NOHA”.

3.47 *Nominal ocular hazard distance (NOHD)*

The distance at which the beam irradiance or radiant exposure falls below the appropriate corneal maximum permissible exposure (MPE). If the NOHD includes the possibility of optically-aided viewing, this is termed the “extended NOHD”.

3.48 *Operation*

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

3.49 *Optical density*

Logarithm to base ten of the reciprocal of the transmittance (IEV 45-20-100).

Symbol:  $D$

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

3.50 *Protective enclosure*

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

3.51 *Protective housing*

Those portions of a laser product (including a product incorporating an embedded laser) which are designed to prevent human access to laser radiation in excess of the prescribed AEL (generally installed by a manufacturer).

3.52 *Pulse radiation*

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

3.53 *Pulsed laser*

A laser which delivers its energy in the form of a single pulse or a train of pulses. In this standard, the duration of a pulse is less than 0.25 s.

3.54 *Radiance*

The radiant power per unit area of a radiation surface per unit solid angle of emission.

Symbol:  $L$

$$L = \frac{d^2\Phi}{d\Omega \cdot dA \cdot \cos\theta}$$

SI unit: watt per steradian per square metre ( $\text{W} \cdot \text{sr}^{-1} \cdot \text{m}^{-2}$ )

Note. — This definition is a simplified version of IEC 45-05-150, sufficient for the purpose of this standard. In cases of doubt the IEC definition should be followed.

3.55 *Radiant energy*

Energy emitted, transferred, or received in the form of radiation. (IEC 45-05-130.)

Symbol:  $Q$

SI unit: joule (J)

3.56 *Radiant exposure*

At a point on a surface, the radiant energy incident on an element of a surface divided by the area of that element (usually expressed in  $\text{J} \cdot \text{m}^{-2}$ ).

Symbol:  $H$

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

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

3.57 *Radiant flux; radiant power*

Power emitted, transferred, or received in the form of radiation (IEC 45-05-135).

Symbol:  $\Phi_e, \Phi, P$

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

SI unit: watt (W)

3.58 *Reflectance*

The ratio of total reflected radiant power to total incident radiant power (IEC 45-20-040).

Symbol:  $\rho$

3.59 *Remote interlock connector*

A connector which permits the connection of external controls placed apart from other components of the laser product (see Sub-clause 4.4).

3.60 *Safety interlock*

An automatic device associated with the protective housing of a laser product to prevent human access to Class 3 or Class 4 laser radiation when that portion of the housing is removed.

3.61 *Scanning laser radiation*

Laser radiation having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference.

**3.62 Service**

The performance of those procedures or adjustments described in the manufacturer's service instructions, which may affect any aspect of the product's performance. It does not include maintenance or operation.

**3.63 Service connection**

An access point in a laser fibre optic transmission system which is designed for service and requires a tool to disconnect.

**3.64 Service panel**

An access panel that is designed to be removed or displaced for service.

**3.65 Specular reflection**

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

**3.66 Surveying laser products**

See *Alignment laser product*, Sub-clause 3.4.

**3.67 Tool**

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

**3.68 Transmittance**

The ratio of total transmitted radiant power to total incident radiant power (IEV 45-20-085).

Symbol:  $\tau$

**3.69 Visible radiation: light**

Any radiation capable of causing a visual sensation directly (IEV 45-05-025).

*Note.* — In this standard, this is taken to mean electromagnetic radiation for which the wavelengths of the monochromatic components lie between 400 nm and 700 nm.

## SECTION TWO — MANUFACTURING REQUIREMENTS

**4. Engineering specifications****4.1 General remarks**

Laser products require certain built-in safety features, depending on the class to which they have been assigned by the manufacturer. The requirements for these are given in Sub-clauses 4.2 to 4.10. The manufacturer shall ensure that the personnel responsible for the classification of laser products and systems have received training to an appropriate level which allows them to understand the full implications of the classification scheme.

#### 4.1.1 *Modification*

If the modification of a previously classified laser product affects any aspect of the product's performance or intended functions within the scope of this standard, the person or organization performing any such modification is responsible for ensuring the reclassification and relabelling of the laser product.

#### 4.2 *Protective housing*

##### 4.2.1 *General*

Each laser product (including embedded lasers), regardless of its class, shall have a protective housing or enclosure which, when in place, prevents human access during operation to:

- a) laser radiation in excess of the accessible emission limits of Class 1 wherever and whenever human access to laser radiation exceeding the limits of Class 1 is not necessary for the performance of the function(s) of the product; and
- b) laser radiation in excess of the accessible emission limits of Class 2 or Class 3 wherever and whenever human access to laser radiation exceeding the limits of Class 2, or Class 3 respectively, is not necessary for the performance of the function(s) of the product.

##### 4.2.2 *Service*

Any parts of the housing or enclosure of a laser product (including embedded laser products) that can be removed or displaced for service and which would allow access to laser radiation in excess of the AEL assigned and are not interlocked (see Sub-clause 4.3) shall be secured in such a way that removal or displacement of the parts requires the use of tools.

##### 4.2.3 *Removable laser system*

If an embedded laser product or a laser system can be removed from its protective housing or enclosure and operated without modification, the laser shall comply with the manufacturing requirements of Clauses 4 and 5 that are appropriate to its class, except for laser products which are sold to other manufacturers for use as components of any system for subsequent sale which are not subject to this standard, since the final product will itself be subject to this standard.

#### 4.3 *Safety interlocks*

- 4.3.1 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 1, Class 2 or Class 3A and the AEL of the class assigned, shall be provided with a safety interlock. The safety interlock shall 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 resetting of the interlock shall not in itself restore emission values above the AEL of the class assigned.

NOTE. For information see X.6.

- 4.3.2 If a deliberate override mechanism is provided, the manufacturer shall also provide adequate instructions about safe methods of working. It shall not be possible to leave the override in operation when the access panel is returned to its normal position. The interlock shall be clearly associated with a label conforming to Sub-clause 5.9.2. Use of the override shall give rise to a distinct visible or audible warning whenever the laser is energized or capacitor banks are not fully discharged, whether or not the access panel is removed or displaced. Visible warnings shall be clearly visible through protective eyewear specifically designed or specified for the wavelength(s) of the accessible laser radiation.

#### 4.4 *Remote interlock connector*

Each Class 3A, Class 3B and Class 4 laser product shall incorporate a remote interlock connector. When the terminals of the connector are open-circuited, the accessible radiation shall not exceed the AEL for Class 1 and Class 2.

NOTE. For information see X.7.

#### 4.5 *Key control*

Each Class 3B and Class 4 laser product shall incorporate a key-operated master control.

NOTE. For information see X.8.

The key shall be removable and the laser shall not be operable when the key is removed. In this standard, the term "key" includes any other control devices, such as magnetic cards, cipher combinations, etc.

#### 4.6 *Laser radiation emission warning*

Each Class 3B and Class 4 laser product shall give an audible or visible high integrity warning when it is switched on or if capacitor banks of pulsed lasers are being charged or have not been positively discharged. Any visible warning device shall be clearly visible through protective eyewear specifically designed for the wavelength(s) of the emitted laser radiation. If the laser and its energy source are separately housed, and if they can be operated at a separation distance greater than 2 m, they shall each be provided with audible or visible warning devices. The visible warning device(s) shall be located so that viewing does not require exposure to laser radiation in excess of the AEL for Class 1 and Class 2. Distinctive and clearly identifiable sounds which arise from auxiliary equipment (such as pumps or fans) and which are uniquely associated with the emission of laser radiation may be acceptable as an audible warning.

NOTE. For information see X.9.

#### 4.7 *Beam stop or attenuator*

Each Class 3B and Class 4 laser product shall incorporate one or more permanently-attached means (other than laser energy source switch, main connector or key control) capable of preventing human access to laser radiation in excess of the AEL for Class 1 or Class 2. If Class 2 laser radiation is transmitted through the attenuator, see Item a) of Sub-clause 6.1.

NOTE. For information see X.10.

#### 4.8 *Controls*

Each laser product shall have controls located so that adjustment and operation do not require exposure to laser radiation in excess of the AEL for Class 1 and Class 2.

#### 4.9 *Viewing optics*

Any viewing optics, viewport or display screen incorporated in a laser product shall provide sufficient attenuation to prevent human access to laser radiation in excess of the AEL for Class 1, and for any shutter or variable attenuator incorporated in the viewing optics, viewport or display screen, a means shall be provided to:

- a) prevent human access to laser radiation in excess of the AEL for Class 1 when the shutter is opened or the attenuation varied;
- b) prevent opening of the shutter or variation of the attenuator when exposure to laser radiation in excess of the AEL for Class 1 is possible.

#### 4.10 *Scanning safeguard*

Laser products intended to emit scanned radiation, and classified on this basis, shall not, as a result of scan failure or of variation in either scan velocity or amplitude, permit human access to laser radiation in excess of the AEL for the assigned class.

### 5. **Labelling**

#### 5.1 *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.

If the size or design of the product makes labelling impractical, the label should be included with the user information or on the package.

#### 5.2 *Class 1*

Each Class 1 laser product shall have affixed an explanatory label (Figure 15, page 99), bearing the words:

CLASS 1 LASER PRODUCT  
TO BS 7192

NOTE. For information see X.11.

#### 5.3 *Class 2*

Each Class 2 laser product shall have affixed a warning label (Figure 14, page 98) and an explanatory label (Figure 15) bearing the words:

LASER RADIATION  
DO NOT STARE INTO BEAM  
CLASS 2 LASER PRODUCT  
TO BS 7192

NOTE. For information see X.12.

#### 5.4 *Class 3A*

Each Class 3A laser product shall have affixed a warning label (Figure 14) and an explanatory label (Figure 15) bearing the words:

LASER RADIATION  
DO NOT STARE INTO BEAM OR VIEW  
DIRECTLY WITH OPTICAL INSTRUMENTS  
CLASS 3A LASER PRODUCT  
TO BS 7192

NOTE. For information see X.13.

### 5.5 *Class 3B*

Each Class 3B laser product shall have affixed a warning label (Figure 14) and an explanatory label (Figure 15) bearing the words:

LASER RADIATION  
AVOID EXPOSURE TO BEAM  
CLASS 3B LASER PRODUCT  
TO BS 7192

NOTE. For information see X.14.

### 5.6 *Class 4*

Each Class 4 laser product shall have affixed a warning label (Figure 14) and an explanatory label (Figure 15) bearing the words:

LASER RADIATION  
AVOID EYE OR SKIN EXPOSURE TO  
DIRECT OR SCATTERED RADIATION  
CLASS 4 LASER PRODUCT  
TO BS 7192

NOTE. For information see X.15.

### 5.7 *Aperture label*

Each 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

### 5.8 *Radiation output information*

Each laser product (except those of Class 1) shall be described on the explanatory label (Figure 15) by statements of the maximum output of laser radiation, the pulse duration (if appropriate) and the emitted wavelength(s).

### 5.9 *Labels for access panels*

#### 5.9.1 *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:

CAUTION — LASER RADIATION WHEN OPEN

In addition, this label shall bear the words:

- a) DO NOT STARE INTO BEAM  
if the accessible radiation does not exceed the AEL for Class 2;
- b) DO NOT STARE INTO BEAM OR  
VIEW DIRECTLY WITH OPTICAL INSTRUMENTS  
if the accessible radiation does not exceed the AEL for Class 3A;
- c) AVOID EXPOSURE TO BEAM  
if the accessible radiation does not exceed the AEL for Class 3B;
- d) AVOID EYE OR SKIN EXPOSURE TO  
DIRECT OR SCATTERED RADIATION  
if the accessible radiation exceeds the limits for Class 3B at any wavelength.



### 5.9.2 *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 and shall bear the words:

**CAUTION — LASER RADIATION WHEN OPEN  
AND INTERLOCKS DEFEATED**

In addition, this label shall bear the words specified in Items *a*), *b*), *c*), and *d*) of Sub-clause 5.9.1.

### 5.10 *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".

## 6. **Other informational requirements**

### 6.1 *Information for the user*

Manufacturers of laser products shall provide (or see to the provision of) as an integral part of any user instruction or operation manual which is regularly supplied with the laser product:

- a*) Adequate instructions for proper assembly, maintenance, and safe use including clear warnings concerning precautions to avoid possible exposure to hazardous laser radiation.
- b*) A statement in appropriate units of beam divergence for collimated beams, pulse duration 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, those conditions associated with the product known to result in unintentional mode-locking shall be specified).
- c*) Legible reproductions (colour optional) of all required labels and hazard warnings to be affixed to the laser product or provided with the laser product. The corresponding position of each label affixed to the product shall be indicated or, if provided with the product, a statement that such labels could not be affixed to the product but were supplied with the product and a statement of the form and manner in which they were supplied shall be provided.
- d*) A clear indication in the manual of all locations of laser apertures.
- e*) 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."
- f*) In the case of laser products that do not incorporate the laser energy source necessary for laser emission, a statement of the compatibility requirements for a laser energy source to ensure safety.

## 6.2 *Purchasing and servicing information*

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, a legible reproduction (colour optional) of the required classification labels (Sub-clauses 5.3 to 5.6) to be affixed.
- b) To servicing dealers and distributors, and to others upon request, adequate instructions for service adjustments and service procedures for each laser product model which includes clear warnings and precautions to be taken to avoid possible exposure to radiation and a schedule of maintenance necessary to keep the product in compliance; and, in all such service instructions a listing of those controls and procedures which could be utilized by persons other than the manufacturer or his agents to increase accessible emission levels of radiation, and a clear description of the location of displaceable portions of the protective housing which could allow access to laser radiation in excess of the accessible limits in Tables I, II, III and IV. The instructions shall include protective procedures for service personnel, and legible reproductions (colour optional) of required labels and hazard warnings.

## 7. **Additional requirements for specific laser products**

### 7.1 *Medical laser products*

Each medical laser product shall comply with all of the applicable requirements for laser products of its class. In addition, the manufacturers shall:

- a) For Class 3B or Class 4 laser products, incorporate in each medical laser product a means for the measurement of the level of that laser radiation intended for irradiation of the human body with an error in measurement of no more than  $\pm 20\%$ . Indication of the measurement shall be in SI units.
- b) Supply with each medical laser product instructions specifying a procedure and schedule for calibration of the measurement system.
- c) Provide a target-indicating device for Class 3B and Class 4 laser products.

### 7.2 *Laser fibre optic transmission system\**

Laser systems which employ fibre optic transmission shall have cable service connections which require a tool for disconnection if the AEL for Class 1 is exceeded when disconnected and if such cable connections form part of the protective housing. Consideration should also be given to incorporating mechanical beam attenuators at connectors if service is anticipated in an unsupervised work area. A length of fibre optic cable may sufficiently attenuate the transmitted laser radiant power such that the length of the cable itself forms part of the protective housing.

\* At the October 1979 Ottawa meeting of Sub-Committee 46E: Fibre Optics, a working group on fibre optic safety was established.

## 8. Tests

### 8.1 General

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

Specific use requirements may impose additional tests.

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

Equivalent tests or procedures are acceptable.

### 8.2 Measurements of laser radiation for determining classification

Measurement of laser radiation levels may be necessary to classify a laser product in accordance with Sub-clause 9.1. Measurements are unnecessary when the physical characteristics and limitations of the laser source place the laser product or laser installation clearly in a particular class.

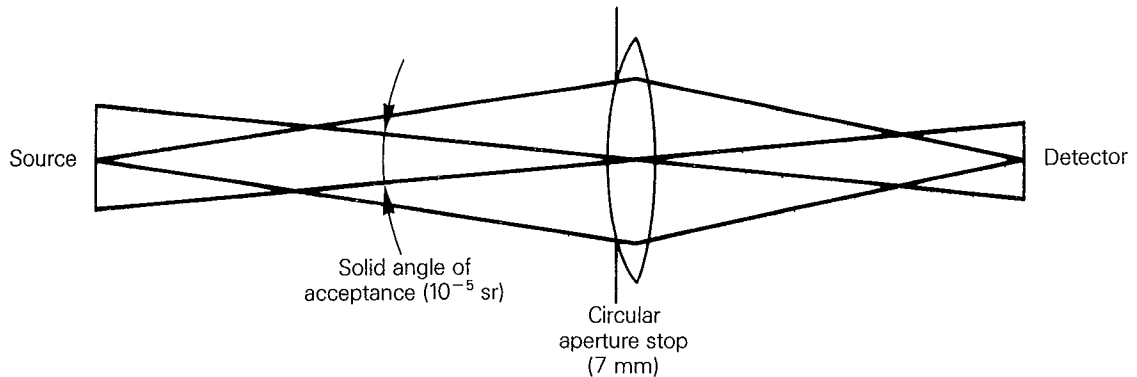
Measurements shall be made under the following conditions:

- a) Under those conditions and procedures which 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 service instructions adjusted in combination to result in the maximum accessible level of radiation.
- c) At points in space to which human access is possible during operation for measurement of accessible emission levels, (e.g. if operation may require removal of portions of the protective housing and defeat of safety interlocks, measurements shall be made at points accessible in that product configuration).
- d) With the measuring instrument detector so positioned and so oriented with respect to the laser product as to result in the maximum detection of radiation by the instrument.
- e) 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.
- f) For values expressed in radiant power (W) or radiant energy (J), within a circular aperture stop of diameter 80 mm (to simulate the collection by an optical instrument of a stationary laser beam).
- g) For values expressed in irradiance ( $\text{W.m}^{-2}$ ) or radiant exposure ( $\text{J.m}^{-2}$ ) average over a circular stop according to the limiting apertures of table VI. For the measurement distance see 9.3(f).

NOTE. For information see X.16.

- h)* For values expressed as radiance or integrated radiance by measuring the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 mm and within an effective solid angle of acceptance of  $10^{-5}$  sr as illustrated in the diagram below. The measurement distance between the apparent source and the circular aperture stop shall be 100 mm.

NOTE. For information see X.17.



- i)* For scanned laser radiation within a stationary circular aperture stop having a 7 mm diameter. (The resulting temporal variation of detected radiation shall be considered as a pulse or series of pulses.)
- j)* For the wavelength range from 400 nm to 1400 nm within an effective solid angle of acceptance of  $5 \times 10^{-4}$  sr, except for measurements of radiance or integrated radiance.
- k)* Appropriate provision shall be made to avoid or to eliminate the contribution of collateral radiation to the measurement.

## 9. Classification

### 9.1 Introduction

Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of a laser beam, the hazards arising in their use vary widely. It is impossible to regard lasers as a single group to which common safety limits can apply.

### 9.2 Description of laser classes

NOTE. For information see X.18.

Laser products are grouped into four general classes for each of which accessible emission limits (AELs) are specified.

Class 1 lasers are those that are inherently safe (so that the maximum permissible exposure level cannot be exceeded under any condition) or are safe by virtue of their engineering design. The upper limits are given in Table I and are derived from the most limiting MPE values.

Class 2 lasers are low power devices emitting visible radiation (in the wavelength range 400 nm to 700 nm) and which may operate in either CW or pulsed mode. The output power or energy of these systems is limited to the AEL's of Class 1 for exposure durations up to 0.25 s. For a CW laser the limit is 1 mW.

Note. — These lasers are not intrinsically safe but eye protection is normally afforded by aversion responses including the blink reflex.

Class 3A lasers are those that have an output power of up to 5 mW for CW lasers or five times the Class 2 limit for repetitively-pulsed and scanning lasers for the spectral region of 400 nm to 700 nm. However, the irradiance at any point in the visible beam must not exceed  $25 \text{ W} \cdot \text{m}^{-2}$  (see Table III). For other spectral regions the laser radiation must not exceed five times the AEL for Class 1 and the output irradiance or radiant exposure listed in Table III must also not be exceeded.

*Note.* — Direct intrabeam viewing of Class 3A laser beams with optical aids (e.g., binoculars, telescopes) may be hazardous. For lasers emitting in the range from 400 nm to 700 nm, protection to the unaided eye is afforded by aversion responses including the blink reflex.

NOTE. For information see X.19.

Class 3B lasers may emit visible and/or invisible radiation at levels not exceeding the AEL's specified in Table IV. CW lasers may not exceed 0.5 W and the radiant exposure from pulsed lasers must be less than  $10^5 \text{ J} \cdot \text{m}^{-2}$ .

*Note.* — Direct intrabeam viewing near these devices is always hazardous. Viewing unfocused pulsed laser radiation by diffuse reflection is not hazardous and under certain conditions CW laser beams may safely be viewed via a diffuse reflector. These conditions are:

- a) a minimum viewing distance of 13 cm;
- 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.

Class 4 lasers are high power devices with output powers exceeding the AELs specified in Table IV for Class 3B.

*Note* — Visible and IR-A Class 4 lasers are capable of producing hazardous diffuse reflections. All Class 4 lasers may cause skin injuries and could also constitute a fire hazard. Their use requires extreme caution.

NOTE. For information see X.20.

### 9.3 Classification procedure

It is the responsibility of the manufacturer or his agent to provide correct classification of a laser product. 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 which results in its allocation to the highest appropriate class. The accessible emission limit (AELs) for Class 1, Class 2, Class 3A and Class 3B (listed in order of increasing hazard) are given in Tables I, II, III and IV respectively.

The values of the four correction factors used are given in the notes to the tables (Tables I to IV) as functions of the wavelength and the emission duration.

The rules for the assignment of a laser to a particular class are as follows:

#### a) Radiation of a single wavelength

A single wavelength laser product is assigned to a class when the laser radiation passing through the aperture exceeds the accessible emission limits (AELs) of all lower classes but does not exceed that of the class assigned.

#### b) Radiation of multiple wavelengths

1) A laser product emitting two or more wavelengths in spectral regions, shown as additive in Table V, is assigned to a class when the sum of the ratios of the laser radiation passing through the aperture to the AELs for those wavelengths is greater than unity for all lower classes but does not exceed unity for the class assigned.

2) A laser product emitting two or more wavelengths not shown as additive in Table V is assigned to a class when the laser radiation passing through the aperture exceeds the AELs of all lower classes for any wavelength but does not exceed the AEL for the class assigned for any wavelength.

c) *Human accessibility considerations for classification; protective housing*

If through any port in the protective housing a portion of the body can be exposed to laser radiation by failure mode, insertion of optical probes, or insertion of a portion of the body, the laser shall be classified, labelled, and otherwise treated in conformity with the radiation existing at that site and the portion of the body to which that radiation can be presented.

d) *Class 1 dual limits*

In the wavelength range greater or equal to 400 nm but less than 1400 nm dual limits exist for Class 1 laser products. A laser product is classified as Class 1 if it complies with at least one of the two sets of AEL values (radiant power or energy; radiance or integrated radiance) given in Table I.

e) *Angular subtense*

For the purpose of classification the angular subtense  $\alpha$  used as a basis for distinguishing direct intrabeam viewing from extended source viewing must be calculated (or measured) at the smallest possible distance from the apparent source but not less than 100 nm. (See limiting angular subtense  $\alpha_{\min}$  3.39.)

f) *Location for measurement of irradiance or radiant exposure*

For the case of intrabeam viewing, two locations for the measurement of the irradiance ( $\text{W.m}^{-2}$ ) or the radiant exposure ( $\text{J.m}^{-2}$ ) are used in this standard:

- i) generally, the measurement is taken at the point of the maximum accessible irradiance or radiant exposure; and
- ii) in the wavelength range of 400 to 1400 nm a minimum measurement distance of 100 mm between the apparent source and the circular aperture stop may be used, unless distances of less than 100 mm between the apparent source and the human eye are intended in the design of the laser product. In case of a minimum measurement distance of 100 mm, the measurement distance shall be recorded on the explanatory label.

NOTE. For information see X.21.

Two time bases are used in this standard:

- a) 1000 s for laser radiation of wavelengths greater than 400 nm unless intentional viewing was inherent in the design or function of the laser product; and
- b) 30 000 s for laser radiation of wavelengths less than or equal to 400 nm and for laser radiation of wavelengths greater than 400 nm where intentional viewing was inherent in the design or function of the laser product.

If the reduced duration is used, this should be recorded on the label with the intended use of the laser.

#### 9.4 *Repetitively pulsed or modulated lasers*

Since there are only limited data on multiple pulse exposure criteria, caution must be used in the evaluation of exposure to repetitively pulsed radiation. The following methods shall be used to determine the AEL to be applied to repetitive exposures.

9.4.1 The AEL for wavelengths 400 nm to 1400 nm is determined by using the most restrictive of requirements a), b) and c) or a), b) and d) as appropriate. For other wavelengths the AEL is determined by using the most restrictive of requirements a) and b).

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

- b) The average power for a pulse train of duration  $T$  shall not exceed the power corresponding to the AEL given in Tables I, II, III, and IV, respectively for a single pulse of duration  $T$ .
- c) If the individual pulse duration is less than  $10^{-5}$  s, for pulse trains where the instantaneous pulse repetition frequency (PRF) is greater than 1 Hz, the AEL (in Tables I, II, III, and IV) applicable to each pulse shall be taken as the AEL of a single isolated pulse reduced by the PRF Correction Factor  $C_5$  (shown in Figure 7, page 90) which varies with the pulse repetition frequency  $N$ :

for  $N$  between 1 Hz and 278 Hz,  $C_5 = 1/\sqrt{N}$

for  $N$  greater than 278 Hz,  $C_5 = 0.06$

*Note.* — The instantaneous PRF is the reciprocal of the shortest pulse interval in a train of pulses.

- d) If the individual pulse duration is greater than  $10^{-5}$  s, and where the instantaneous pulse repetition frequency is greater than one Hz, the following formula shall be used:

$$AEL_{(single)} = \frac{AEL_{(nt)}}{n}$$

where:

$n$  = number of pulses in the train during the time used for classification

$t$  = individual pulse width

$AEL_{(nt)}$  = AEL applicable to a pulse of width  $nt$  seconds

9.4.2 For pulse trains having a non-uniform or variable PRF (e.g. pulse rate modulation) the maximum instantaneous PRF attainable shall be applied and the AEL applicable to each pulse calculated as in Sub-clause 9.4.1.

9.4.3 When a pulse train consists of a pattern or group of 10 or less individual pulses, the pattern being repeated at regular or semi-regular intervals, the analysis can be simplified by reducing each individual group of pulses to a single equivalent pulse and applying the provisions of Sub-clauses 9.4.1 and 9.4.2. The method of determining the equivalent pulse shall be as follows:

- a) If the group or pattern pulse width is less than  $10^{-5}$  s, the equivalent single pulse shall have a pulse width equal to the narrowest pulse width within the group, and a radiant exposure equal to the total radiant exposure of the group.
- b) If the group or pattern pulse width is greater than  $10^{-5}$  s, the equivalent single pulse shall have a pulse width equal to the sum of the individual pulse widths within the group, with a radiant exposure equal to the total radiant exposure of the group.
- c) In some cases the AEL derived by the methods outlined above may lead to a more restrictive situation than would have resulted if the provisions of Sub-clauses 9.4.1 and 9.4.2 had been applied to the original pulse train, under these circumstances the less restrictive AEL value may be taken.

When a pulse train consists of a pattern or group of more than 10 pulses repeated at regular or semi-regular intervals, the provisions of Sub-clauses 9.4.1 and 9.4.2 shall be applied with a PRF determined by the highest instantaneous PRF within the group.

TABLE I  
Accessible emission limits for Class 1 laser products

| Wave-length<br>$\lambda$ (nm) |       | Emission<br>Duration<br>$t$ (s)                                                           | $<10^{-9}$                                          | $10^{-9}$<br>to<br>$10^{-7}$                                        | $10^{-7}$<br>to<br>$1.8 \times 10^{-5}$                          | $1.8 \times 10^{-5}$<br>to<br>$5 \times 10^{-5}$                                    | $5 \times 10^{-5}$<br>to<br>10                                                      | 10<br>to<br>$10^3$                                                    | $10^3$<br>to<br>$10^4$ | $10^4$<br>to<br>$3 \times 10^4$ |
|-------------------------------|-------|-------------------------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------|------------------------|---------------------------------|
| 180 to 302.5                  |       |                                                                                           | $2.4 \times 10^{-5}$ J                              |                                                                     |                                                                  |                                                                                     |                                                                                     |                                                                       |                        |                                 |
| 302.5 to 315                  |       |                                                                                           | $7.9 \times 10^{-7}$ C <sub>2</sub> J ( $t > T_1$ ) |                                                                     |                                                                  |                                                                                     |                                                                                     |                                                                       |                        |                                 |
| 315 to 400                    |       |                                                                                           | $7.9 \times 10^{-7}$ C <sub>1</sub> J ( $t < T_1$ ) |                                                                     |                                                                  |                                                                                     |                                                                                     |                                                                       |                        |                                 |
| 400<br>to<br>550              | and * | 200 W<br><br>$10^{11}$ W . m <sup>-2</sup> sr <sup>-1</sup>                               | $2 \times 10^{-7}$ J                                | $10^5 t^{0.33}$ J . m <sup>-2</sup> sr <sup>-1</sup>                | $7 \times 10^{-4} t^{0.75}$ J                                    | $7.9 \times 10^{-3}$ J                                                              | $3.9 \times 10^{-3}$ J                                                              | $7.9 \times 10^{-7}$ C <sub>2</sub> J                                 | $3.9 \times 10^{-7}$ W |                                 |
|                               |       |                                                                                           | $2 \times 10^{-7}$ J                                | $10^5 t^{0.33}$ J . m <sup>-2</sup> sr <sup>-1</sup>                | $7 \times 10^{-4} t^{0.75}$ J . m <sup>-2</sup> sr <sup>-1</sup> | $2.1 \times 10^5$ J . m <sup>-2</sup> sr <sup>-1</sup>                              | $3.9 \times 10^{-3}$ C <sub>3</sub> J ( $t > T_2$ )                                 | $21$ W . m <sup>-2</sup> sr <sup>-1</sup>                             |                        |                                 |
| 550<br>to<br>700              | and * | 200 W<br><br>$10^{11}$ W . m <sup>-2</sup> sr <sup>-1</sup>                               | $2 \times 10^{-7}$ J                                | $10^5 t^{0.33}$ J . m <sup>-2</sup> sr <sup>-1</sup>                | $7 \times 10^{-4} t^{0.75}$ J . ( $t < T_2$ )                    | $3.9 \times 10^{-3}$ C <sub>3</sub> J ( $t > T_2$ )                                 | $2.1 \times 10^5$ C <sub>3</sub> J . m <sup>-2</sup> sr <sup>-1</sup> ( $t > T_2$ ) | $3.9 \times 10^{-7}$ C <sub>3</sub> W                                 |                        |                                 |
|                               |       |                                                                                           | $2 \times 10^{-7}$ J                                | $10^5 t^{0.33}$ J . m <sup>-2</sup> sr <sup>-1</sup>                | $7 \times 10^{-4} t^{0.75}$ J . m <sup>-2</sup> sr <sup>-1</sup> | $2.1 \times 10^5$ C <sub>3</sub> J . m <sup>-2</sup> sr <sup>-1</sup> ( $t > T_2$ ) | $21$ C <sub>3</sub> W . m <sup>-2</sup> sr <sup>-1</sup>                            |                                                                       |                        |                                 |
| 700<br>to<br>1050             | and * | 200 C <sub>4</sub> W<br><br>$10^{11}$ C <sub>4</sub> W . m <sup>-2</sup> sr <sup>-1</sup> | $2 \times 10^{-7}$ C <sub>4</sub> J                 | $10^5 t^{0.33}$ C <sub>4</sub> J . m <sup>-2</sup> sr <sup>-1</sup> | $7 \times 10^{-4} t^{0.75}$ C <sub>4</sub> J                     | $1.2 \times 10^{-4}$ C <sub>4</sub> W                                               | $3.9 \times 10^4 t^{0.75}$ C <sub>4</sub> J . m <sup>-2</sup> sr <sup>-1</sup>      | $6.4 \times 10^3$ C <sub>4</sub> W . m <sup>-2</sup> sr <sup>-1</sup> |                        |                                 |
|                               |       |                                                                                           | $2 \times 10^{-7}$ C <sub>4</sub> J                 | $10^5 t^{0.33}$ C <sub>4</sub> J . m <sup>-2</sup> sr <sup>-1</sup> | $7 \times 10^{-4} t^{0.75}$ C <sub>4</sub> J                     | $3.9 \times 10^4 t^{0.75}$ C <sub>4</sub> J . m <sup>-2</sup> sr <sup>-1</sup>      | $6.4 \times 10^3$ C <sub>4</sub> W . m <sup>-2</sup> sr <sup>-1</sup>               |                                                                       |                        |                                 |
| 1050<br>to<br>1400            | and * | $2 \times 10^3$ W<br><br>$5 \times 10^{11}$ W . m <sup>-2</sup> sr <sup>-1</sup>          | $2 \times 10^{-6}$ J                                | $5 \times 10^5 t^{0.33}$ J . m <sup>-2</sup> sr <sup>-1</sup>       | $3.5 \times 10^{-3} \times t^{0.75}$ J                           | $6 \times 10^{-4}$ W                                                                | $1.9 \times 10^5 t^{0.75}$ J . m <sup>-2</sup> sr <sup>-1</sup>                     | $3.2 \times 10^4$ W . m <sup>-2</sup> sr <sup>-1</sup>                |                        |                                 |
|                               |       |                                                                                           | $2 \times 10^{-6}$ J                                | $5 \times 10^5 t^{0.33}$ J . m <sup>-2</sup> sr <sup>-1</sup>       | $3.5 \times 10^{-3} \times t^{0.75}$ J                           | $1.9 \times 10^5 t^{0.75}$ J . m <sup>-2</sup> sr <sup>-1</sup>                     | $3.2 \times 10^4$ W . m <sup>-2</sup> sr <sup>-1</sup>                              |                                                                       |                        |                                 |
| 1400 to $10^5$                |       | $8 \times 10^4$ W                                                                         | $8 \times 10^{-5}$ J                                | $4.4 \times 10^{-3} t^{0.25}$ J                                     | $8 \times 10^{-4}$ W                                             |                                                                                     |                                                                                     |                                                                       |                        |                                 |
| $10^5$ to $10^6$              |       | $10^7$ W                                                                                  | $10^{-2}$ J                                         | $0.56 t^{0.25}$ J                                                   | $0.1$ W                                                          |                                                                                     |                                                                                     |                                                                       |                        |                                 |

\* See Item d) of Sub-clause 9.3 for Class 1 dual limits requirements.

NOTE. For information see X.22.