

Safety of laser products —

Part 4: Laser guards

ICS 13.280; 31.260

National foreword

This British Standard is the UK implementation of EN 60825-4:2006+A2:2011. It is identical with IEC 60825-4:2006, incorporating amendments 1:2008 and 2:2011. It supersedes BS EN 60825-4:2006+A1:2008 which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated in the text by A1 A1.

The UK participation in its preparation was entrusted to Technical Committee EPL/76, Optical radiation safety and laser equipment.

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

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2006

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ISBN 978 0 580 67294 1

Amendments/corrigenda issued since publication

Date	Comments
31 May 2010	Implementation of IEC amendment 1:2008 with CENELEC endorsement A1:2008
31 July 2011	Implementation of IEC amendment 2:2011 with CENELEC endorsement A2:2011

Safety of laser products
Part 4: Laser guards
(IEC 60825-4:2006)

Sécurité des appareils à laser
Partie 4: Protecteurs pour lasers
(CEI 60825-4:2006)

Sicherheit von Lasereinrichtungen
Teil 4: Laserschutzwände
(IEC 60825-4:2006)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of document 76/342/FDIS, future edition 2 of IEC 60825-4, prepared by IEC TC 76, Optical radiation safety and laser equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60825-4 on 2006-10-01.

This European Standard supersedes EN 60825-4:1997 + A1:2002 + A2:2003.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2007-07-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2009-10-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60825-4:2006 was approved by CENELEC as a European Standard without any modification.

Foreword to amendment A1

The text of document 76/383/FDIS, future amendment 1 to IEC 60825-4:2006, prepared by IEC TC 76, Optical radiation safety and laser equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A1 to EN 60825-4:2006 on 2008-09-01.

The following dates were fixed:

- latest date by which the amendment has to be
implemented at national level by publication of
an identical national standard or by endorsement (dop) 2009-06-01
- latest date by which the national standards conflicting
with the amendment have to be withdrawn (dow) 2011-09-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of amendment 1:2008 to the International Standard IEC 60825-4:2006 was approved by CENELEC as an amendment to the European Standard without any modification.

Foreword to amendment A2

The text of document 76/428/CDV, future amendment 2 to IEC 60825-4:2006, prepared by IEC TC 76, Optical radiation safety and laser equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A2 to EN 60825-4:2006 on 2011-05-03.

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The following dates were fixed:

- latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2012-02-03
- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 2014-05-03

Endorsement notice

The text of amendment 2:2011 to the International Standard IEC 60825-4:2006 was approved by CENELEC as an amendment to the European Standard without any modification.

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INTRODUCTION

At low levels of irradiance or radiant exposure, the selection of material and thickness for shielding against laser radiation is determined primarily by a need to provide sufficient optical attenuation. However, at higher levels, an additional consideration is the ability of the laser radiation to remove guard material – typically by melting, oxidation or ablation; processes that could lead to laser radiation penetrating a normally opaque material.

IEC 60825-1 deals with basic issues concerning laser guards, including human access, interlocking and labelling, and gives general guidance on the design of protective housings and enclosures for high-power lasers.

This part of IEC 60825 deals with protection against laser radiation only. Hazards from secondary radiation that may arise during material processing are not addressed.

Laser guards may also comply with standards for laser protective eyewear, but such compliance is not necessarily sufficient to satisfy the requirements of this standard.

Where the term “irradiance” is used, the expression “irradiance or radiant exposure, as appropriate” is implied.

SAFETY OF LASER PRODUCTS –

Part 4: Laser guards

1 Scope

This part of IEC 60825 specifies the requirements for laser guards, permanent and temporary (for example for service), that enclose the process zone of a laser processing machine, and specifications for proprietary laser guards.

This standard applies to all component parts of a guard including clear (visibly transmitting) screens and viewing windows, panels, laser curtains and walls. Requirements for beam path components, beam stops and those other parts of a protective housing of a laser product which do not enclose the process zone are contained in IEC 60825-1.

In addition this part of IEC 60825 indicates:

- a) how to assess and specify the protective properties of a laser guard; and
- b) how to select a laser guard.

2 Normative references

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.

[A1] IEC 60825-1:2007, *Safety of laser products – Part 1: Equipment classification and requirements* **[A1]**

Amendment 1 (1997)

Amendment 2 (2001)

ISO 12100-1:2003, *Safety of machinery – Basic concepts, general principles for design – Part 1: Basic terminology, methodology*

ISO 12100-2:2003, *Safety of machinery – Basic concepts, general principles for design – Part 2: Technical principles and specifications*

ISO 11553-1:2005, *Safety of machinery – Laser processing machines – Safety requirements*

[A1] ISO 14121-1:2007, *Safety of machinery – Risk assessment – Part 1: Principles*

ISO 13849-1:2006, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design* **[A1]**

3 Definitions

For the purpose of this part of IEC 60825, the following definitions apply in addition to the definitions given in IEC 60825-1.

3.1

active guard protection time

for a given laser exposure of the front surface of an active laser guard, the minimum time, measured from the issue of an active guard termination signal, for which the active laser guard can safely prevent laser radiation accessible at its rear surface from exceeding the class 1 AEL

3.2

active guard termination signal

the signal issued by an active guard in response to an excess exposure of its front surface to laser radiation and which is intended to lead to automatic termination of the laser radiation

NOTE The action of a safety interlock becoming open circuit is considered a "signal" in this context.

3.3

active laser guard

a laser guard which is part of a safety-related control system. The control system generates an active guard termination signal in response to the effect of laser radiation on the front surface of the laser guard

3.4

foreseeable exposure limit

FEL

the maximum laser exposure on the front surface of the laser guard, within the maintenance inspection interval, assessed under normal and reasonably foreseeable fault conditions

3.5

front surface

the face of the laser guard intended for exposure to laser radiation

3.6

laser guard

a physical barrier which limits the extent of a danger zone by preventing laser radiation accessible at its rear surface from exceeding the class 1 AEL

3.7

laser processing machine

a machine which uses a laser to process materials and is within the scope of ISO 11553-1

3.8

laser termination time

the maximum time taken, from generation of an active guard termination signal, for the laser radiation to be terminated

NOTE Laser termination time does not refer to the response of an active laser guard but to the response of the laser processing machine, in particular the laser safety shutter.

3.9

maintenance inspection interval

the time between successive safety maintenance inspections of a laser guard

3.10

passive laser guard

a laser guard which relies for its operation on its physical properties only

3.11

process zone

the zone where the laser beam interacts with the material to be processed

3.12

proprietary laser guard

a passive or active laser guard, offered by its manufacturer as a guard with a specified protective exposure limit

3.13

protective exposure limit

PEL

the maximum laser exposure of the front surface of a laser guard which is specified to prevent laser radiation accessible at its rear surface from exceeding the class 1 AEL

NOTE 1 In practice, there may be more than one maximum exposure.

NOTE 2 Different PELs may be assigned to different regions of a laser guard if these regions are clearly identifiable (for example a viewing window forming an integral part of a laser guard).

3.14

rear surface

any surface of a laser guard that is remote from the associated laser radiation and usually accessible to the user

3.15

reasonably foreseeable

an event (or condition) when it is credible and its likelihood of occurrence (or existence) cannot be disregarded

3.16

safety maintenance inspection

documented inspection performed in accordance with manufacturer's instructions

3.17

temporary laser guard

a substitute or supplementary active or passive laser guard intended to limit the extent of the danger zone during some service operations of the laser processing machine

4 Laser processing machines

This clause specifies the requirements for laser guards that enclose the process zone and are supplied by the laser processing machine manufacturer.

4.1 Design requirements

A laser guard shall satisfy ISO 12100-2 with respect to the general requirements for guards and also the more specific requirements with regard to its location and method of fixture. In addition, the following specific laser requirements shall be met.

4.1.1 General requirements

A laser guard, in its intended location, shall not give rise to any associated hazard at or beyond its rear surface when exposed to laser radiation up to the foreseeable exposure limit.

NOTE 1 Examples of associated hazards include: high temperature, the release of toxic materials, fire, explosion, electricity.

NOTE 2 See Annex B for assessment of foreseeable exposure limit.

4.1.2 Consumable parts of laser guards

Provision shall be made for the replacement of parts of a laser guard prone to damage by laser radiation.

NOTE An example of such a part would be a sacrificial or interchangeable screen.

4.2 Performance requirements

4.2.1 General

When the front surface of a laser guard is subjected to exposure to laser radiation at the foreseeable exposure limit, the laser guard shall prevent laser radiation accessible at its rear surface from exceeding the class 1 AEL at any time over the period of the maintenance inspection interval. For automated laser processing machines, the minimum value of the maintenance inspection interval shall be 8 h.

This requirement shall be satisfied over the intended lifetime of the laser guard under expected conditions of operation.

NOTE 1 This requirement implies both low transmission of laser radiation and resistance to laser-induced damage.

NOTE 2 Some materials may lose their protective properties due to ageing, exposure to ultraviolet radiation, certain gases, temperature, humidity and other environmental conditions. Additionally, some materials will transmit laser radiation under high-intensity laser exposure, even though there may be no visible damage (i.e. reversible bleaching).

4.2.2 Active laser guards

- a) The active guard protection time shall exceed the laser termination time up to the foreseeable exposure limits.
- b) The generation of an active guard termination signal shall give rise to a visible or audible warning. A manual reset is required before laser emission can recommence.

NOTE See Annex C.2 for an elaboration of terms.

4.3 Validation

If the laser processing machine manufacturer chooses to make a laser guard, the manufacturer shall confirm that the guard complies with the design requirements of 4.1 and can satisfy the performance requirements set out in 4.2.

NOTE See Annex A for guidance on the design and selection of laser guards.

4.3.1 Validation of performance

4.3.1.1 The complete laser guard, or an appropriate sample of the material of construction of the laser guard, shall be tested at each FEL identified.

NOTE 1 A table of predetermined PELs for common combinations of lasers and guarding materials, together with suitable testing procedures shall be issued as an informative annex in a future amendment to this standard. This could provide a simple alternative to direct testing for the majority of cases.

NOTE 2 See Annex B for the assessment of FEL.

4.3.1.2 For testing purposes, the FEL exposure shall be achieved either:

- a) by calculating or measuring the exposure and reproducing the conditions; or
- b) without quantifying the FEL, by creating the machine conditions under which the FEL is produced.

The condition of the laser guard or sample shall be such as to replicate those physical conditions of the front surface permitted within the scope of the routine inspection instructions and within the service life of the guard, which minimize the laser radiation protective properties of the laser guard (for example wear and tear and surface contamination) (see 4.4.2).

4.4 User information

4.4.1 The manufacturer shall document and provide to the user the maintenance inspection interval for the laser guard, and details of inspection and test procedures, cleaning, replacement or repair of damaged parts, together with any restrictions of use.

4.4.2 The manufacturer shall document and provide to the user instructions that after any actuation of the safety control system of an active guard, the cause shall be investigated, checks shall be made for damage, and the necessary remedial action to be taken before resetting the control system.

5 Proprietary laser guards

This clause specifies the requirements to be satisfied by suppliers of proprietary laser guards.

5.1 Design requirements

A proprietary laser guard shall not create any associated hazard at or beyond its rear surface when exposed to laser radiation up to the specified PEL when used as specified in the user information (see 5.6).

5.2 Performance requirements

The accessible laser radiation at the rear surface of the laser guard shall not exceed the class 1 AEL when its front surface is subjected to laser radiation at the specified PEL. For an active laser guard, this requirement shall apply to laser radiation accessible over the period of the active guard protection time, measured from the moment an active guard termination signal is issued.

This requirement shall be satisfied over the intended lifetime of the guard under expected service conditions.

5.3 Specification requirements

The full specification of a PEL shall include the following information:

- a) the magnitude and variation with time of irradiance or radiant exposure at the front surface of the laser guard (in units of Wm^{-2} or Jm^{-2} respectively), specifying any upper limit to the area of exposure;
- b) the overall duration of exposure under these conditions;
- c) the wavelength for which this PEL applies;
- d) the angle of incidence and (if relevant) the polarization of the incident laser radiation;

- e) any minimum dimensions to the irradiated area (for example as might apply to an active laser guard with discrete sensor elements so that a small diameter laser beam could pass through the guard undetected);
- f) for an active laser guard, the active guard protection time.

NOTE 1 See Clause B.1 for an elaboration of terms.

NOTE 2 In all cases, a range or set of values can be stated rather than a single value.

NOTE 3 A graphical form of presentation is acceptable (for example irradiance vs. duration with all other parameters constant).

5.4 Test requirements

5.4.1 General

Testing shall be performed using the complete laser guard or an appropriate sample of the material used to construct the guard. In either case, the condition of the guard or sample shall be such as to replicate or exceed the worst permissible physical condition of the front surface, including reduced surface reflection and damage permitted within the scope of the routine maintenance instructions (see 5.6).

The front surface irradiation shall be either as specified by the PEL or, in the case of sample testing, as specified in 5.4.2 below.

When the front surface is subjected to the PEL exposure conditions, the accessible laser radiation measured at the rear surface of the laser guard shall not exceed the class 1 AEL (tests as prescribed in Clause 8 of 60825-1). This requirement applies over the exposure duration specified in the PEL or, in the case of an active guard, over the specified active guard protection time measured from the moment an active guard termination signal is issued.

NOTE In cases where materials opaque at the laser wavelength(s) are used (for example metals), the transmitted radiation will only rise to the class 1 AEL when complete (or almost complete) physical removal of material along a path through to the rear surface has been achieved. In such cases, the rise from zero transmission to a value greatly in excess of the class 1 AEL will therefore be rapid, and sensitive radiation detectors will not be required.

5.4.2 Sample testing

Sample guard testing shall be performed by irradiating the front surface of the guard material using the procedure and methodology as specified in Annex D.

5.5 Labelling requirements

5.5.1 All labelling shall be placed on the rear surface of the guard.

5.5.2 The rear surface of the guard shall be clearly identified if the orientation of the guard is important.

5.5.3 If only part of the front surface of the guard is a laser guard, this area shall be clearly identified by a bold coloured outline and words to indicate the outer boundary of the laser guard.

5.5.4 The labelling shall state the full PEL specification.

5.5.5 The manufacturer's name, the date and place of manufacture according to ISO 11553-1, and a statement of compliance with this standard shall be provided.

5.6 User information

In addition to the specifications listed in 5.3, the following information shall be supplied to the user by the manufacturer of a proprietary laser guard:

- a) a description of the permitted uses of the laser guard;
- b) a description of the form of mounting and connection of the laser guard;
- c) information on the installation of the laser guard – for active laser guards this shall include interface and supply requirements for the guard;
- d) maintenance requirements, including for example details of inspection and test procedures, cleaning, replacement or repair of damaged parts;
- e) instructions, that after any actuation of the safety control system of an active guard, the cause shall be investigated, checks shall be made for damage, and the necessary remedial action to be taken before resetting the control system;
- f) the labels in 5.5 and their locations. If only part of the front surface of the guard is a laser guard, this area shall be identified;
- g) a statement of compliance with this standard.

Annex A (informative)

General guidance on the design and selection of laser guards

A.1 Design of laser guards

A.1.1 Passive laser guards

Examples of a passive laser guard include the following.

- a) A metal panel relying on thermal conduction, if necessary enhanced by forced air or water cooling, to maintain the surface temperature below its melting point under normal and reasonably foreseeable fault conditions.
- b) A transparent sheet, opaque at the laser wavelength, which is unaffected by low value of laser exposure under normal operation of the laser processing machine.

A.1.2 Active laser guards

Examples of an active laser guard include the following.

- a) A guard, with discrete embedded thermal sensors, which detects overheating.

NOTE The spacing between sensors should be considered in relation to the minimum dimensions of an errant laser beam.

- b) A laser guard comprising two panels between which is contained a pressurized liquid or gaseous medium in combination with a pressure-sensing device capable of detecting the pressure drop following perforation of the front surface.

A.1.3 Hazard indication (passive guards)

Visible indication of exposure of the laser guard to hazardous amounts of laser radiation should be provided where feasible (for example by adding a layer of an appropriate paint on both sides of the laser guard).

A.1.4 Power supply (active guards)

If power is required for the proper functioning of an active guard, its supply should be arranged so that laser operation is not possible in the absence of such power.

A.2 Selection of laser guards

A simple selection process is as follows:

- a) identify the preferred position for the laser guard and estimate the FEL at this position. Annex B gives guidance on the estimation of FEL values;

- b) if necessary, minimize the FEL under fault conditions, preferably by including automatic monitoring in the machine which will detect the fault conditions and limit the exposure time. Examples of alternatives include the following:
- ensure that the laser guard is sufficiently far away from beam focus produced by focusing optics;
 - install vulnerable parts of laser guard (such as viewing windows) away from regions that could be exposed to high irradiance;
 - move the laser guard farther away from the laser process zone;
 - require in the essential servicing documentation for temporary laser guards, additions such as:
 - one or more persons to be present to supervise the condition of the front surface of the laser guard, to reduce the assessed exposure duration of a passive guard;
 - a hold-to-operate controller to be used by the person(s) supervising the condition of the front surface of the laser guard, to reduce the assessed exposure duration of a passive guard;
 - additional local temporary guarding, apertures and beam dumps to be employed, to absorb any powerful errant laser beams;
 - the danger zone to be bounded by errant beam warning devices and the guard placed beyond this zone to reduce the assessed exposure duration;
 - incorporate in the design of the machine, when using temporary laser guards, beam control features to facilitate improved laser beam control during servicing operations, such as:
 - holders for precise location of additional beam forming components (for example turning mirrors) required during servicing;
 - mounts which allow only limited scope for beam steering.

Three options then follow. The order below does not indicate a preference.

A.2.1 Option 1: passive laser guard

This is the simplest option.

NOTE Design and quality control are particularly important considerations where the absorption at the laser wavelength is dominated by a minority additive, such as a dye in a plastic. In such cases, where the manufacturer of the material does not specify the concentration of the absorber or the material optical attenuation at the laser wavelength, samples from the same batch of the material should first be tested as described in 4.3.1.

A.2.2 Option 2: active laser guard

If the FEL cannot be reduced to a value where common guarding materials provide adequate protection in the form of a passive laser guard, an active laser guard can always be used.

A.2.3 Option 3: proprietary laser guard

A proprietary laser guard can be used if the assessed FEL values are less than the PEL values quoted by the laser guard manufacturer.

Annex B (informative)

Assessment of foreseeable exposure limit (FEL)

B.1 General

FEL values may be assessed either by measurement or by calculation (see below).

The standard ISO 14121 provides a general methodology for risk assessment. The assessment should include consideration of cumulative exposure in normal operation (for example during each part processing cycle of the machine) over the maintenance inspection interval.

From this assessment, the most demanding combinations of irradiation, area of exposure and exposure duration should be identified. It is quite likely that several FELs will be identified; for example one condition may maximize the duration of exposure at a relatively low irradiance, while another may maximize the irradiance over a shorter duration of exposure.

The full specification of an FEL comprises the following information.

a) The maximum irradiance at the front surface of the laser guard.

NOTE Irradiance is expressed as the total power or energy divided by the area of the front surface of the guard, or specified limited area, as appropriate.

b) Any upper limit to the area of exposure of the front surface at this level of irradiance.

NOTE No limit to the area would be appropriate for protection against scattered laser radiation while an upper limit to the exposed area would be appropriate for direct exposure to laser beams.

c) The temporal characteristics of the exposure, i.e. whether continuous wave or pulsed laser radiation, and if the latter, then the pulse duration and pulse repetition frequency.

d) The full duration of exposure.

NOTE See Clause B.4 for an elaboration of this term.

e) The wavelength of the radiation.

f) The angle of incidence and (if relevant) the polarization of the radiation.

NOTE 1 Stipulation of angle of incidence is particularly important for laser guards exploiting interference layers to reflect impinging laser radiation.

NOTE 2 CAUTION: At Brewster's angle of incidence "p" polarized radiation is strongly coupled into the surface of the guard.

g) Any minimum dimensions to the irradiated area (for example as might apply to an active laser guard with discrete sensor elements so that a small diameter laser beam could pass through the laser guard undetected).

h) For an active laser guard, the active guard protection time.

B.2 Reflection of laser radiation

B.2.1 Diffuse reflections

Assuming a Lambertian reflector with 100 % reflectivity

$$E_A = \frac{P_o}{\pi} \cdot \frac{\cos\theta}{R^2} \cdot \cos\varphi$$

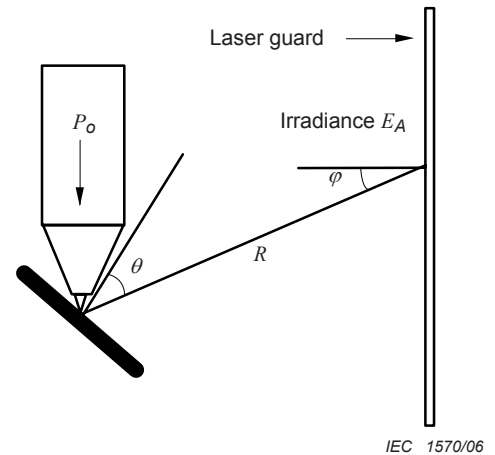


Figure B.1 – Calculation of diffuse reflections

B.2.2 Specular reflections

It is difficult to generalize for the case of specular reflections.

For a circularly symmetric laser beam with a Gaussian distribution, power P_o and diameter d_{63} at the focusing lens, focal length f , the maximum irradiance (at the centre of the Gaussian distribution) in a normal plane distance R from the focus is:

$$E_{AA'} = \frac{4P_o\rho}{\pi d_{63}^2} \left(\frac{f}{R}\right)^2$$

where ρ is the reflectivity of the workpiece surface.

CAUTION: Certain curved surfaces may increase the reflection hazard.

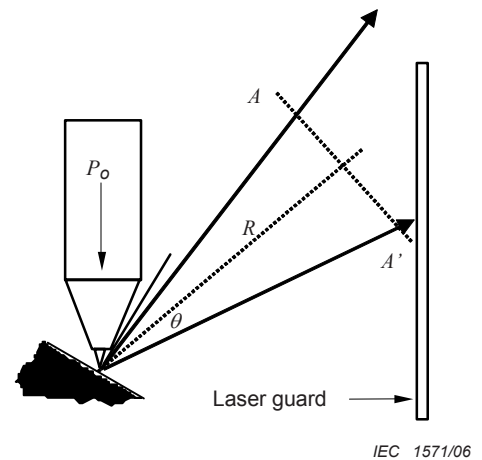


Figure B.2 – Calculation of specular reflections

B.3 Examples of assessment conditions

FELs should be assessed for the worst reasonably foreseeable combination(s) of available laser parameters, workpiece materials, geometry and processes likely to be encountered during normal operation (IEC/TR 60825-14 provides guidance for users).

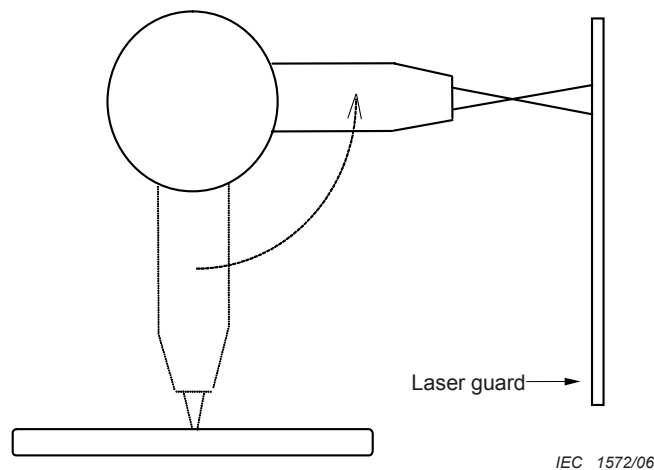


Figure B.3a – Software failure

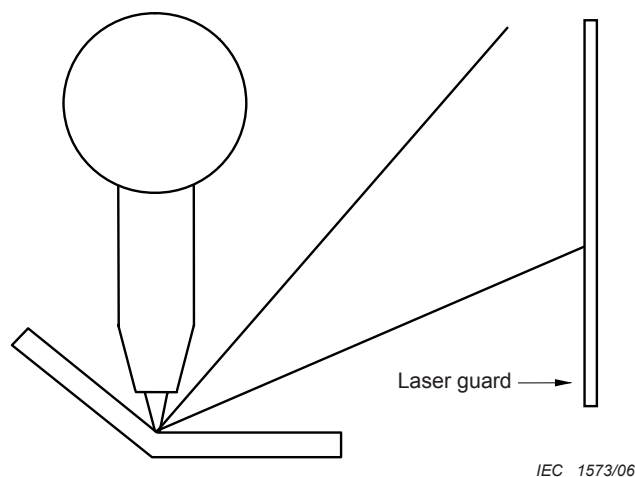


Figure B.3b – Workpiece bends or is inadequately clamped

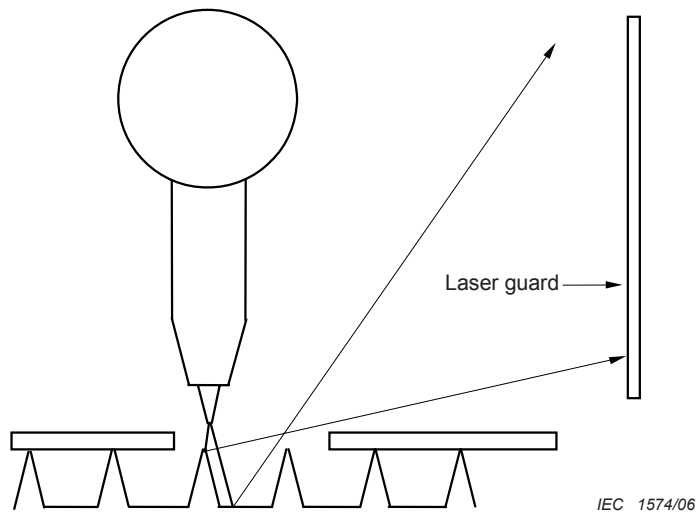


Figure B.3c – Workpiece missing

Figure B.3 – Some examples of a foreseeable fault condition

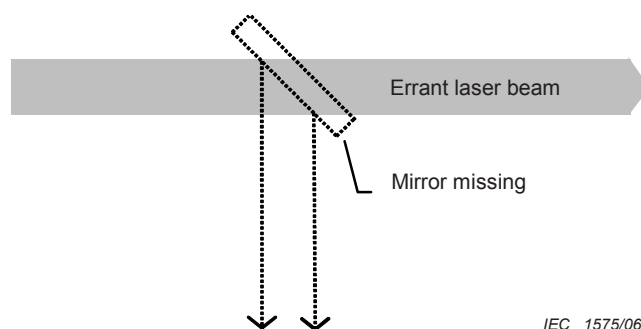


Figure B.4a – Laser is operated with turning mirror missing

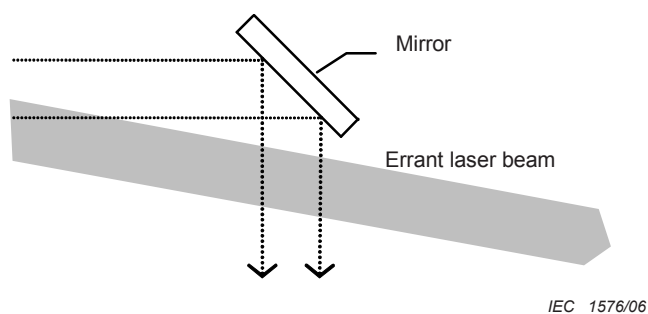


Figure B.4b – Beam displaced off mirror during alignment procedure

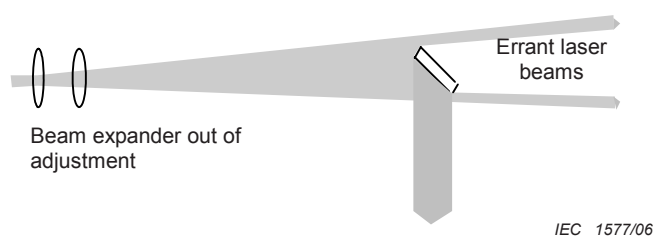


Figure B.4c – Beam expands beyond range of optics

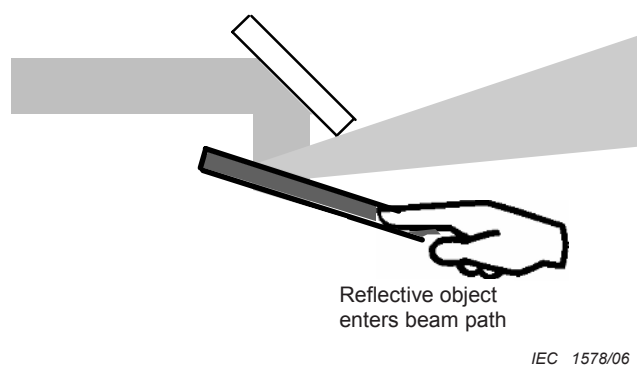


Figure B.4d – Reflective objects intercept laser beam

Figure B.4 – Four examples of errant laser beams that might have to be contained by a temporary guard under service conditions

B.4 Exposure duration

B.4.1 Normal operation

The exposure of a guard to laser radiation during fault-free operation may comprise exposures to low levels of reflected, scattered and transmitted radiation which are repeated on each machine cycle. In this case, the assessed FEL for fault-free operation would encompass the variation in irradiance of the guard during the cycle, repeated for the maximum number of machine cycles within a safety maintenance inspection interval.

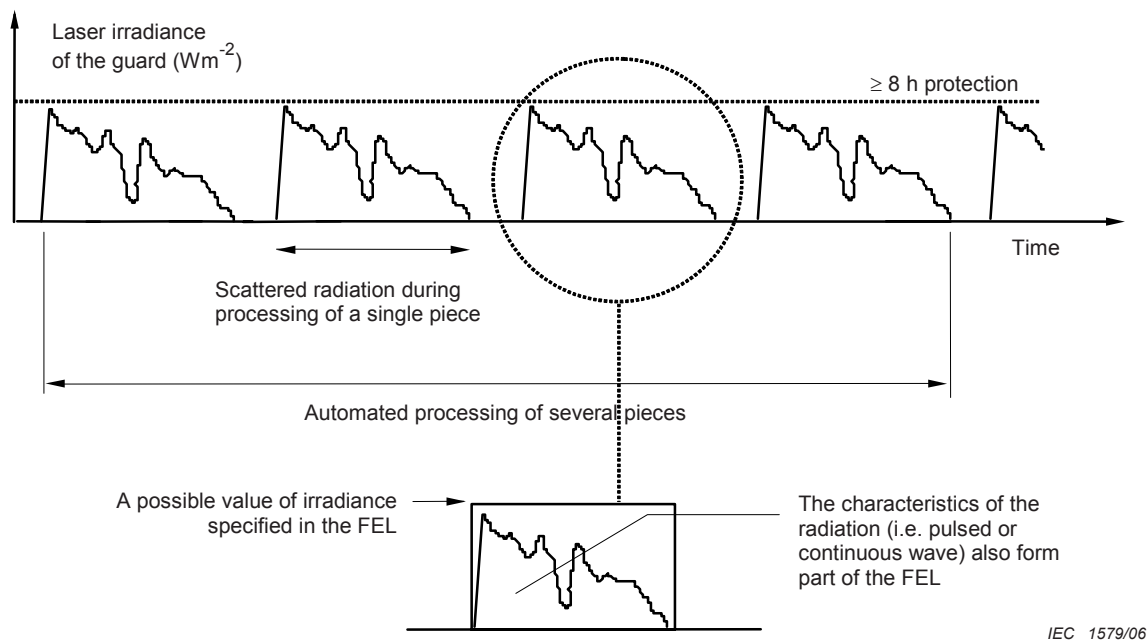


Figure B.5 – Illustration of laser guard exposure during repetitive machine operation

B.4.2 Fault Conditions

A safety control system involving some form of machine monitoring can reduce the time for which the guard must safely contain the radiation hazard under fault conditions. Two examples are given below.

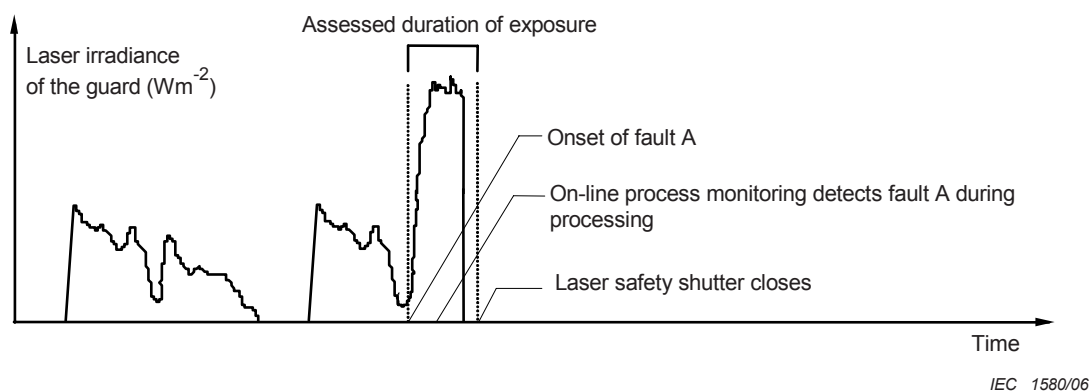


Figure B.6a – Shut-down with on-line machine safety monitoring

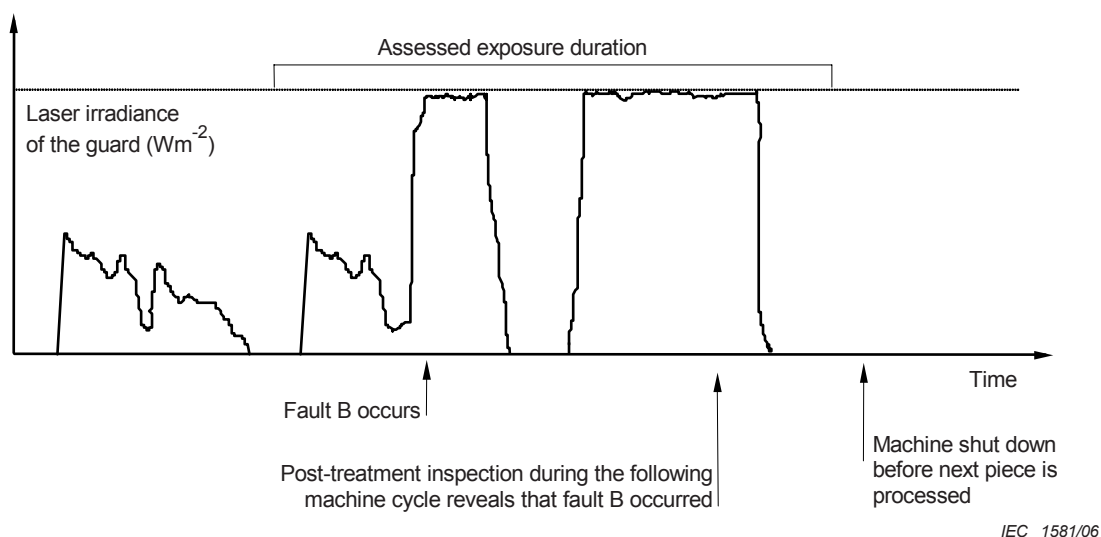


Figure B.6b – Shut-down with off-line machine safety monitoring

Figure B.6 – Two examples of assessed duration of exposure

For reasonably foreseeable fault conditions which are not detected by some safety-related control system, the assessed duration of exposure is the full safety maintenance inspection interval.

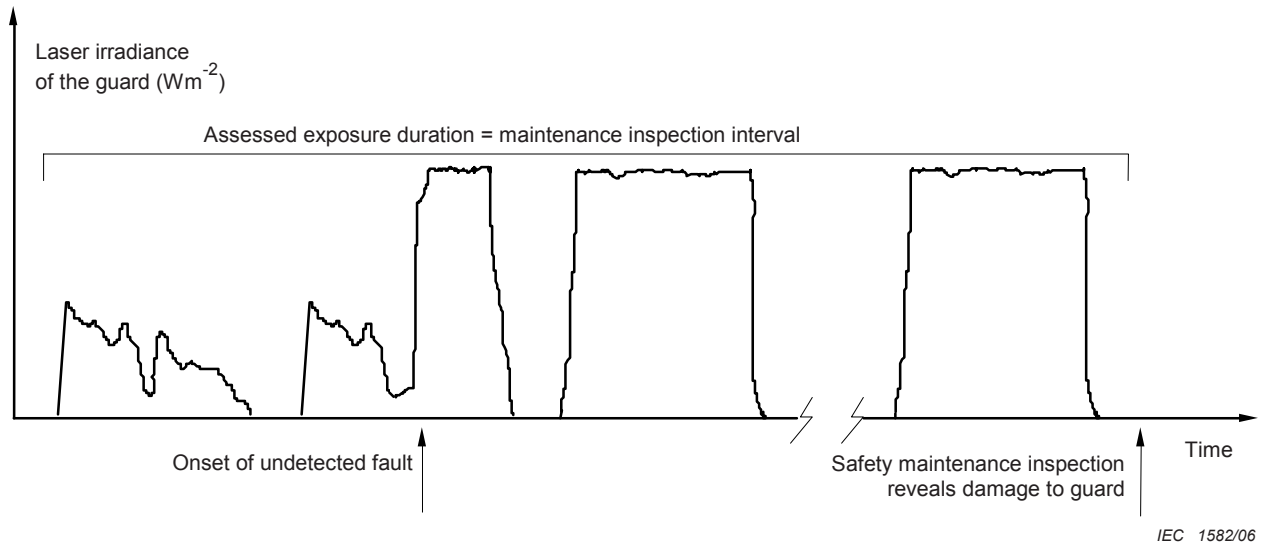


Figure B.7 – Assessed duration of exposure for a machine with no safety monitoring

B.4.3 Servicing operations

The factors which directly affect the time to laser termination measured from the onset of exposure of a temporary guard during servicing operations include:

- the use of a pre-set laser-on time;
- the degree of control over fault conditions;
- provision of persons to supervise the condition of the guard (passive guards);
- provision of a hold-to-operate controller;
- degree of warning provided by the response of the guard to excessive laser exposure (passive guards);
- degree of concealment of the front surface of the guard (passive guards);
- total area of guard to be supervised (passive guards);
- degree of training of service personnel.

A risk assessment should be performed to identify hazardous situations and to assess the foreseeable exposure level. Where human intervention is required to limit the duration of exposure of a temporary guard, a value of not less than 10 s should be used. All reasonably practicable engineering and administrative control measures should be implemented to reduce reliance on temporary screens to provide protection.

B.5 Reference document

ISO 14121:1999, *Safety of machinery – Principles of risk assessment*

Annex C (informative)

Elaboration of defined terms

C.1 Distinction between FEL and PEL

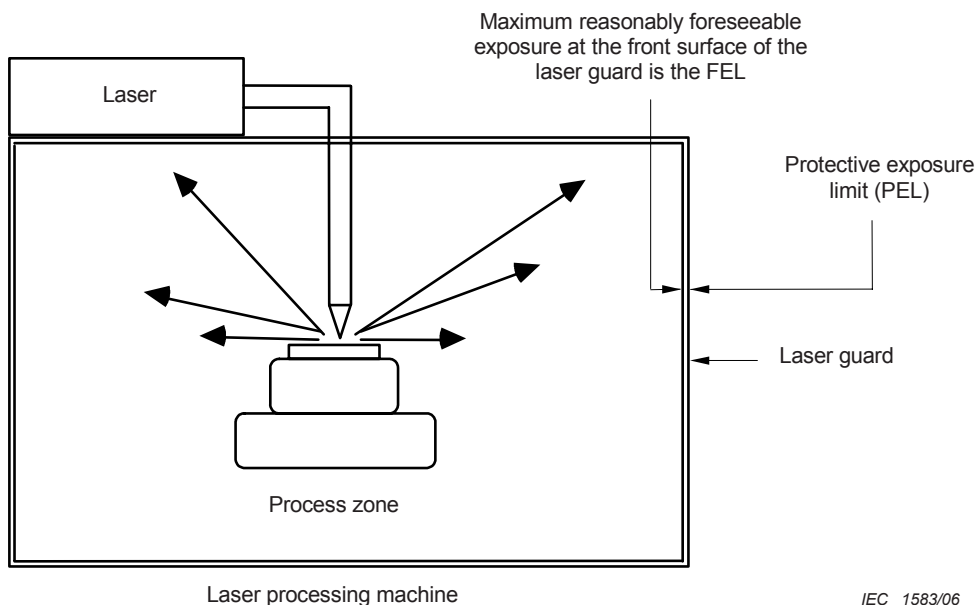


Figure C.1 – Illustration of guarding around a laser processing machine

The foreseeable exposure limit (FEL) at a particular location where a laser guard is to be sited is the maximum exposure estimated by the manufacturer of the laser processing machine, assessed under normal and reasonably foreseeable fault conditions. The FEL value defines the minimum value of the protective exposure limit (PEL) of a laser guard that can be used at that location.

The PEL indicates the capability of a laser guard to protect against incident laser radiation. The manufacturer of the laser processing machine shall perform tests to confirm the adequacy of the laser guards. This can be accomplished by direct testing, or by determining the PEL of the guard, or by purchasing a proprietary laser guard for which the PEL is specified.

C.2 Active guard parameters

An active guard has two essential components:

- a physical barrier, highly attenuating at the laser wavelength, to act as a passive laser guard for low levels of laser radiation (for example diffusely scattered radiation) and to resist the penetration of hazardous levels of incident radiation for a limited (short) time only;