

INTERNATIONAL STANDARD



Safety of laser products – Part 4: Laser guards



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Part 4: Laser guards**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

Part 4: Laser guards

FOREWORD

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IEC 60825-4 has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment. It is an International Standard.

This third edition cancels and replaces the second edition published in 2006, Amendment 1:2008 and Amendment 2:2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Significant amendments have been included and this edition has been prepared for user convenience.

The text of this International Standard is based on the following documents:

Draft	Report on voting
76/704/FDIS	76/711/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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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.

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

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 document applies to all component parts of a guard including clear (visibly transmitting) screens and viewing windows, panels, laser curtains and walls.

In addition, this document indicates

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

NOTE 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.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1:~~2007~~2014, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

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

ISO 12100, *Safety of machinery – General principles for design – Risk assessment and risk reduction*

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

~~ISO 14121-1:2007, Safety of machinery – Risk assessment – Part 1: Principles~~



Documents

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60825-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

access panel

panel which when removed or displaced gives human access to laser radiation

Note 1 to entry: Sheathing around a fibre, tubing used as an enclosure component or any device serving the function of a removable or displaceable panel, can also be an "access panel" within the terms of this definition.

3.2

active guard protection time

minimum time for a given laser exposure of the front (incident) 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

3.3

active guard termination signal

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 1 to entry: The action of a safety interlock becoming open circuit is considered a "signal" in this context.

3.4

active laser guard

laser guard which is part of a safety-related control system whereby failure of the front surface of the laser guard triggers a termination signal. ~~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~~

3.5

beam delivery system

system comprised of all those components, including all optical beam components and potential beam paths and their enclosures, which when combined, transfer laser radiation emitted from the laser radiation generator (the laser) to the workpiece

Note 1 to entry: These components may include all elements for guiding, shaping and switching the laser beam as well as the enclosure of and support for the beam path components. See Annex G for detail on guided beam delivery systems.

3.6

beam diameter

d_{86}

diameter of the smallest circular aperture in a plane perpendicular to the beam axis that contains 86 % of the total laser power (or energy)

Note 1 to entry: In the case of a Gaussian beam (TEM₀₀), d_{86} corresponds to the point where the irradiance (radiant exposure) falls to $1/e^2$ of its central peak value and the second order moments of the power density distribution (ISO 11146-1:2005 3.2).

3.7

beam path component

optical component which lies on a defined beam path

Note 1 to entry: Examples of a beam path component include a beam steering mirror, a focus lens or a fibre optic cable connector.

[SOURCE: IEC 60825-1:2014, 3.16, modified — Example has been removed and Note 1 to entry has been added.]

3.8

beam shaping component

optical component introduced in the beam path to transform the profile or cross-section of the laser beam by means of apertures, or reflective, refractive or diffractive optical components

3.9

beam switching component

optical component or an assembly of components introduced in the beam path to direct or divert, under external control, the beam path along predetermined direction(s) with the external control allowing the beam path to be switched from one predetermined direction to another

3.10

fibre optic cable

optical beam guiding component that enables the transmission of laser radiation along a transparent medium

Note 1 to entry: A fibre optic cable may have a glass or other core that carries the laser radiation and be surrounded by cladding. The outside of the fibre is protected by cladding and may be further protected by additional layers of other material such as a polymer or a metal to protect the fibre from mechanical deformation, the ingress of water, etc. This term also includes other forms of transmission devices such as waveguides.

3.11

foreseeable exposure limit

FEL

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

Note 1 to entry: The full specification of an FEL comprises different elements, including irradiance and exposure duration. More details are given in Annex B.

3.12

front surface

face of the laser guard intended for exposure to laser radiation

3.13

laser guard

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

3.14

laser processing machine

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

3.15

laser termination time

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

Note 1 to entry: 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.

3.16**maintenance inspection interval**

time between successive safety maintenance inspections of a laser guard

3.17**passive guard protection time**

minimum time determined for a laser exposure equal to a specified protective exposure limit (PEL) at the front (incident) surface of a passive laser guard for which the passive laser guard can reliably prevent laser radiation accessible at its rear surface from exceeding the class 1 AEL

3.18**passive laser guard**

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

3.19**process zone**

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

3.20**proprietary laser guard**

passive or active laser guard, offered by ~~its~~ a manufacturer ~~as a~~ of laser guards as an independent product placed on the market with a specified protective exposure limit

3.21**protective exposure limit****PEL**

maximum laser exposure of the front surface of a laser guard which ~~is specified to~~ prevents laser radiation accessible at its rear surface from exceeding the Class 1 AEL ~~for the determined~~ passive or active guard detection time

Note 1 to entry: In practice, there may be more than one maximum laser exposure.

Note 2 to entry: 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).

Note 3 to entry: See 5.3 for the performance requirements and 5.4 for the full specification. The full specification of a PEL comprises different elements, including irradiance and exposure duration.

3.22**rear surface**

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

3.23**reasonably foreseeable**

<event (or condition)> ~~when it is~~ credible and ~~its~~ whose likelihood of occurrence ~~(or existence)~~ cannot be disregarded

3.24**safety maintenance inspection**

documented inspection performed in accordance with manufacturer's instructions

3.25**temporary laser guard**

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~~ Requirements for laser guards

4.1 Requirement

Clause 4 specifies the requirements for laser guards that enclose the process zone and are supplied by the laser processing machine manufacturer.

4.2 Design requirements

4.2.1 Guard requirement

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 for a laser guard.

4.2.2 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 primary laser radiation or secondary optical radiation up to the foreseeable exposure limit. Annex F provides guidance on assessing the suitability of laser guards.

NOTE 1 Examples of associated hazards include high temperature, plasma, excessive ultra-violet radiation, the release of toxic materials, fire, explosion, and electricity.

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

4.2.3 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.

4.3 Performance requirements

4.3.1 General

When the front (incident) 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 intended for unattended and/or unsupervised operation, 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 can 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 if there may be is no visible damage (i.e. reversible bleaching).

4.3.2 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~~ If an active guard detects an excessive exposure, i.e. is triggered, it shall give rise to a visible or audible warning. A manual reset is required before laser emission can recommence.

NOTE See Annex C for an elaboration of terms.

4.4 Validation

4.4.1 General guard 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 and can satisfy the performance requirements set out in 4.3.

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

4.4.2 Validation of performance

4.4.2.1 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—It is intended that a table of predetermined PELs for common combinations of lasers and guarding materials, together with suitable testing procedures, ~~shall~~ will be issued as an informative annex in a future amendment to this document. This could provide a simple alternative to direct testing for the majority of cases.

NOTE 2 See Annex B for the assessment of FEL and Annex C for further elaboration of the terms PEL and FEL.

4.4.2.2 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 4.5.2).

4.5 User information

4.5.1 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.

4.5.2 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, and checks shall be made for damage, ~~and~~. The instructions shall also include the necessary remedial action to be taken before resetting the control system.

5 Proprietary laser guards

5.1 General

Clause 5 specifies the requirements to be satisfied by suppliers of proprietary laser guards.

5.2 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 5.7).

5.3 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 at least

during the passive guard protection time. 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.

5.4 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 W m^{-2} or J m^{-2} , respectively) ~~used to measure its passive guard protection time and mean value and standard deviation of its tested exposure time limit for calculating its passive guard protection time~~, specifying any upper limit to the area of exposure;
- ~~b) the overall duration of exposure under these conditions;~~
- b) the quoted passive guard protection time including safety factor of 0,7 (see Clause D.3 for calculation of the quoted protection time for passive laser guards);
- c) the wavelength(s) 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 plotted against duration with all other parameters constant).

5.5 Test requirements

5.5.1 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 5.7).

The front surface irradiation shall be either as specified by the PEL or, in the case of sample testing, as specified in 5.5.2.

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~~ specified in Clause 5 of IEC 60825-1:2014). 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~~ can rise only 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.

5.5.2 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.

5.6 Labelling requirements

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

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

5.6.3 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.

5.6.4 The labelling shall state the full PEL specification.

5.6.5 The manufacturer's name, the date and place of manufacture in accordance with ISO 11553-1, and a statement of compliance with this document shall be provided.

5.7 User information

In addition to the specifications listed in 5.4, 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, and checks shall be made for damage, ~~and~~. The instructions shall also include the necessary remedial action to be taken before resetting the control system;
- f) the labels in 5.6 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 document.

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.
- c) non-metal panels relying on thermal sublimation without melting and similar materials

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 laser 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 laser 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.2.1 Selection requirements

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:
 - 1) ensure that the laser guard is sufficiently far away from beam focus produced by focusing optics;
 - 2) install vulnerable parts of the laser guard (such as viewing windows) away from regions that could be exposed to high irradiance;
 - 3) move the laser guard farther away from the laser process zone;

- 4) 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 **laser** 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 **laser** 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;
- 5) 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.2.2 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 4.4.1.

A.2.3 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~~ **may** always be used.

A.2.4 Option 3: proprietary laser guard

A proprietary laser guard ~~can~~ **may** 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).

ISO ~~14121~~ 12100 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; see Figure B.1, Figure B.2 and Figure B.3. 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; see Figure B.3 and Figure B.4.

The full specification of an FEL comprises the following information.

- a) The maximum irradiance at the front surface of the laser guard, see Figure B.1 and Figure B.2.

NOTE 1 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 2 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 (CW) or pulsed laser radiation, and if the latter, then the pulse duration and pulse repetition frequency.
- d) The full duration of exposure.

NOTE 3 See Clause B.4 for an elaboration of this term.

- e) The wavelength(s) of the radiation.
- f) The angle of incidence and (if relevant) the polarization of the radiation, see Figure B.1 and Figure B.2.

NOTE ~~1~~ 4 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,

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

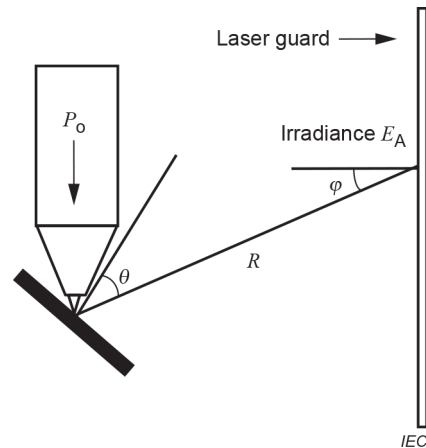


Figure B.1 – Calculation of diffuse reflections

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 at a distance R from the focus is:

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

$$E_{AA'} = \frac{4 \cdot P_o \cdot \rho \left(\frac{f}{R}\right)^2}{\pi \cdot d_{86}^2}$$

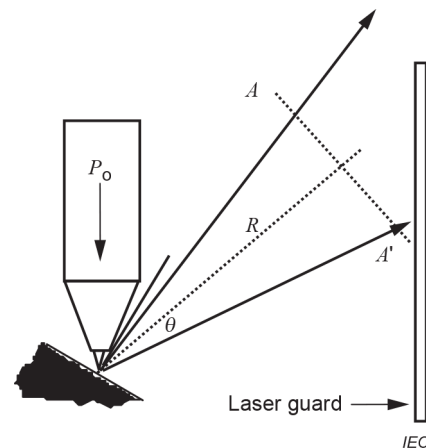


Figure B.2 – Calculation of specular reflections

where ρ is the reflectivity of the workpiece surface.

CAUTION: Certain curved surfaces ~~may~~ can increase the reflection hazard.

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).

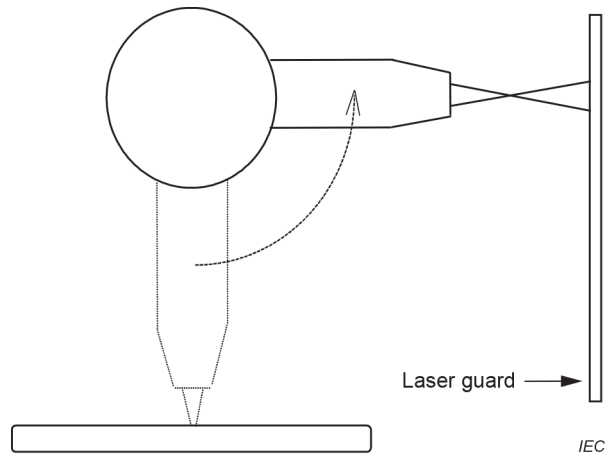


Figure B.3a – Software failure

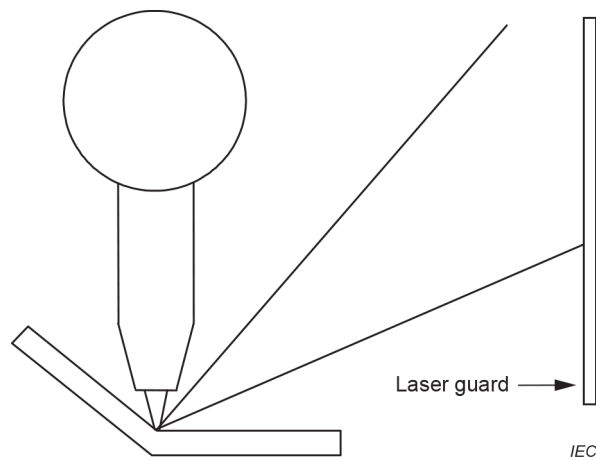


Figure B.3b – Workpiece bends or is inadequately clamped

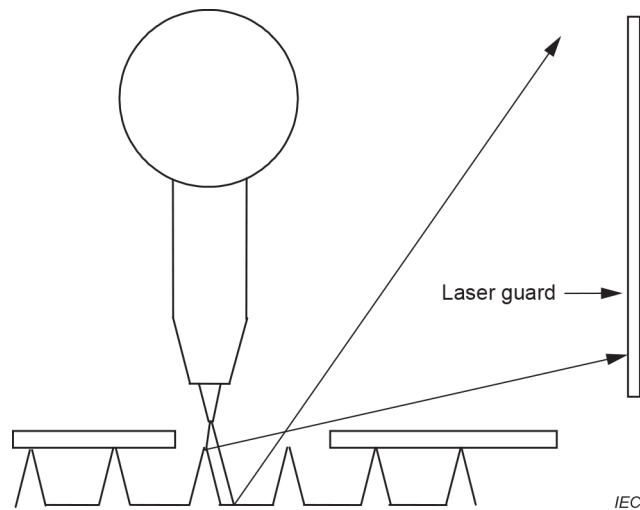


Figure B.3c – Workpiece missing

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

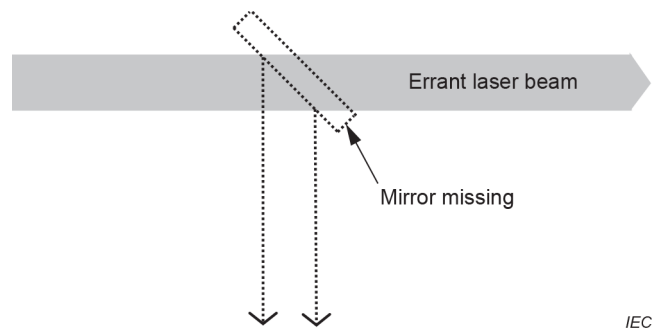


Figure B.4a – Laser is operated with turning mirror missing

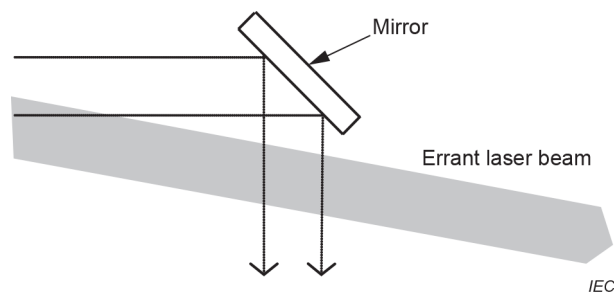


Figure B.4b – Beam displaced off mirror during alignment procedure

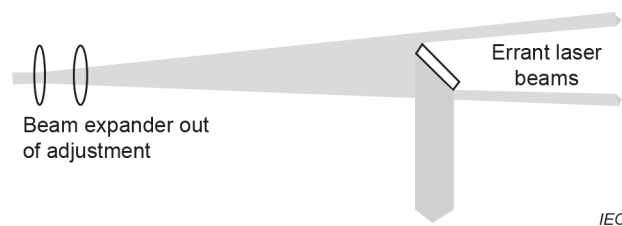


Figure B.4c – Beam expands beyond range of optics

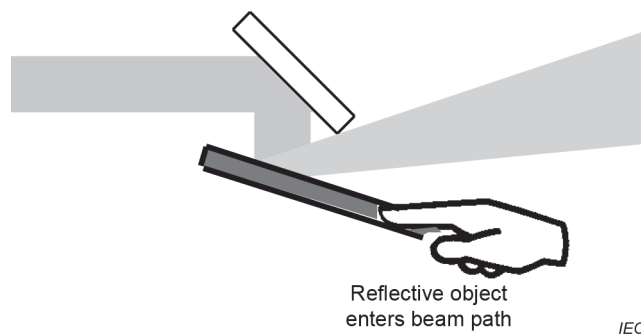


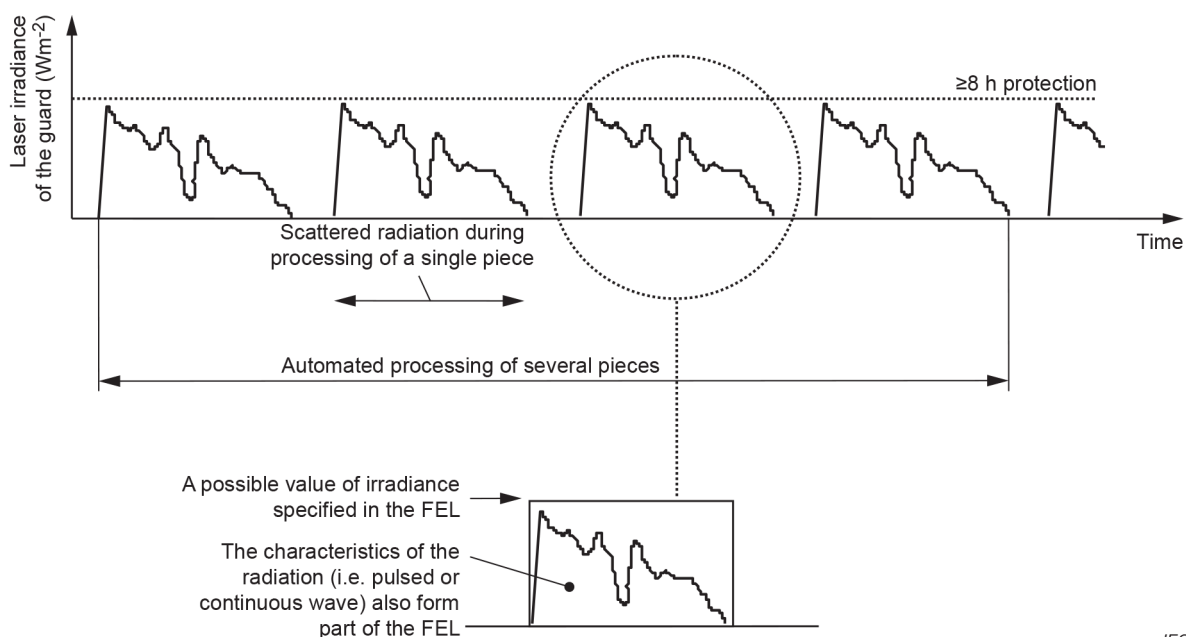
Figure B.4d – Reflective objects intercept laser beam

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, see Figure B.5, repeated for the maximum number of machine cycles within a safety maintenance inspection interval.



IEC

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~~ shall safely contain the radiation hazard under fault conditions. Two examples are given in Figure B.6.

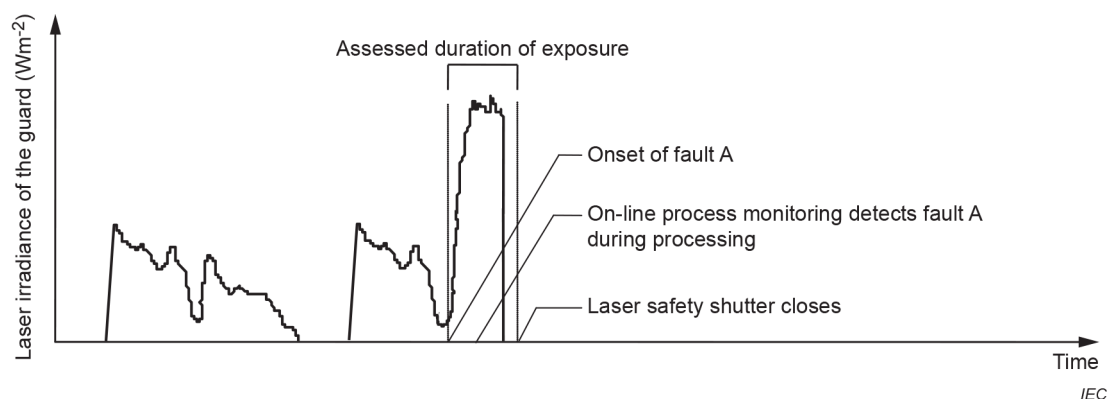


Figure B.6a – Shut-down with on-line machine safety monitoring

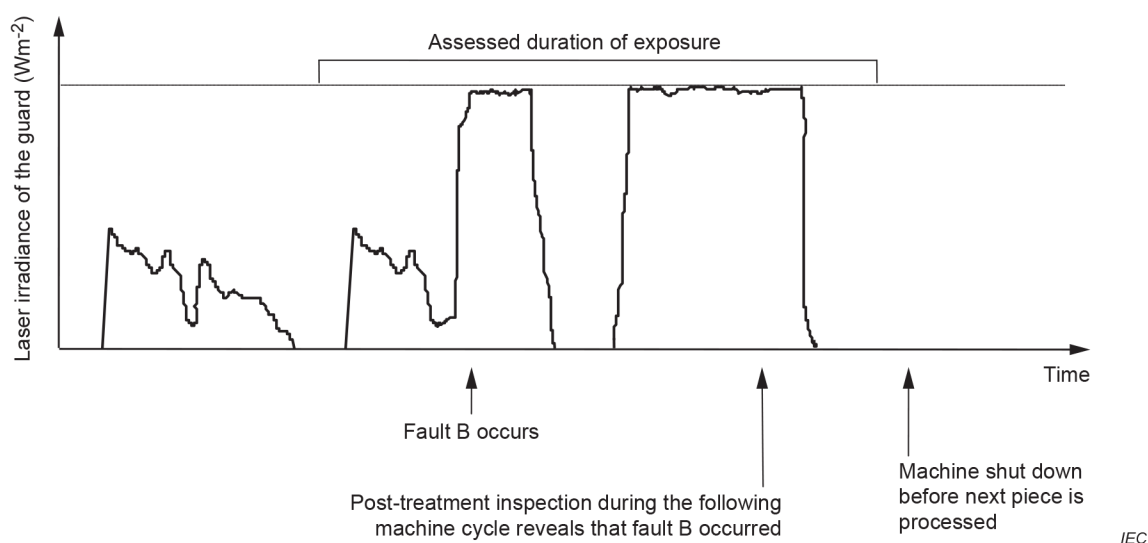


Figure B.6b – Shut-down with off-line machine safety monitoring

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.

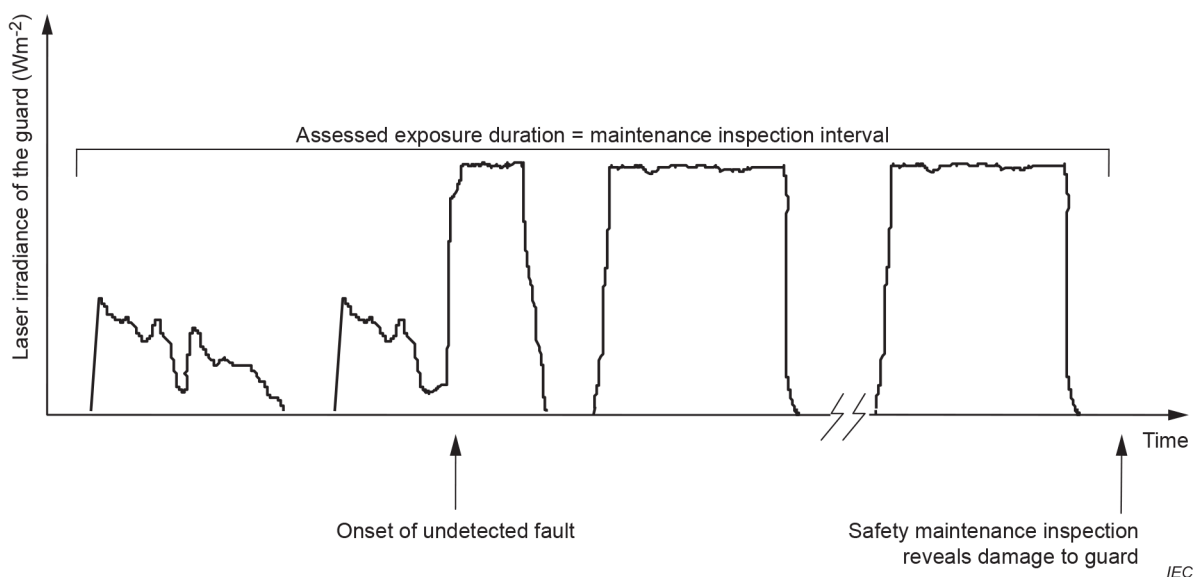


Figure B.7 – Assessed duration of exposure for a machine with no safety monitoring

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 **laser** guards);
- provision of a hold-to-operate controller;
- degree of warning provided by the response of the guard to excessive laser exposure (passive **laser** guards);
- degree of concealment of the front surface of the guard (passive **laser** guards);
- total area of guard to be supervised (passive **laser** 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.

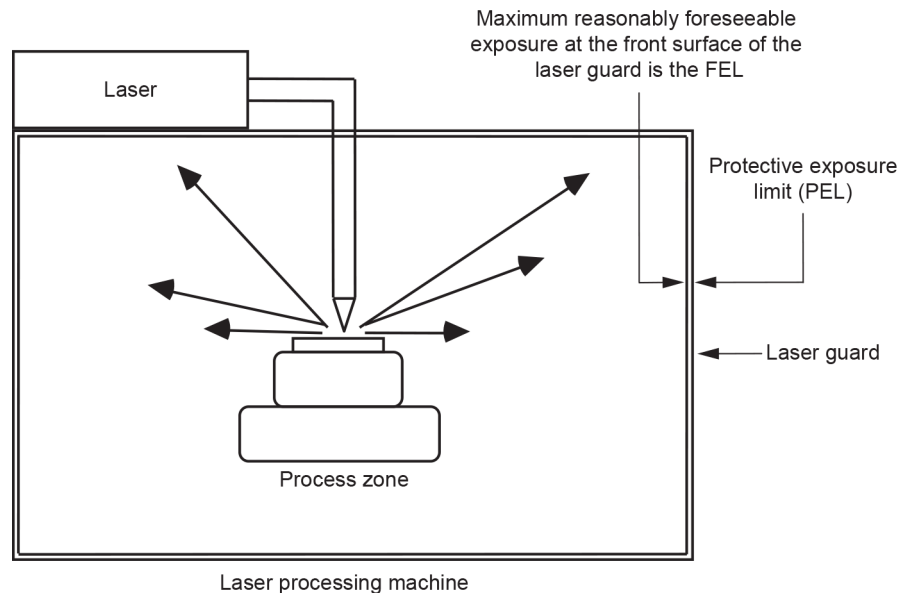
B.5 — Reference document

ISO 14121:1999, Safety of machinery — Principles of risk assessment

Annex C (informative)

Elaboration of defined terms

C.1 Distinction between FEL and PEL



IEC

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, [see Figure C.1](#). 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;
- a safety control system which incorporates a sensor that detects hazardous levels of incident laser radiation either directly or indirectly (for example, by measuring temperature or by detecting some other effect induced by the laser radiation on some part of the laser guard) and then issues a signal to terminate laser emission (for example, by breaking the safety interlock chain, thus switching off the laser source, or by closing a safety shutter).

Laser guards will frequently be subject to low values of laser irradiance during normal operation of a laser processing machine. Since the guard is not threatened by such radiation, the guard

should not react. Instead, the sensor should be set to react only to incident laser radiation that exceeds a threshold value at which the integrity of the laser guard is threatened. There is a time delay between the incident laser radiation exposure exceeding the threshold value and the moment when an active guard termination signal is produced by an active laser guard, see Figure C.2. Similarly, there is a time delay, termed the laser termination time, between the production of the active guard termination signal and the moment when the laser radiation is terminated.

To satisfy the requirements of this standard it is essential that

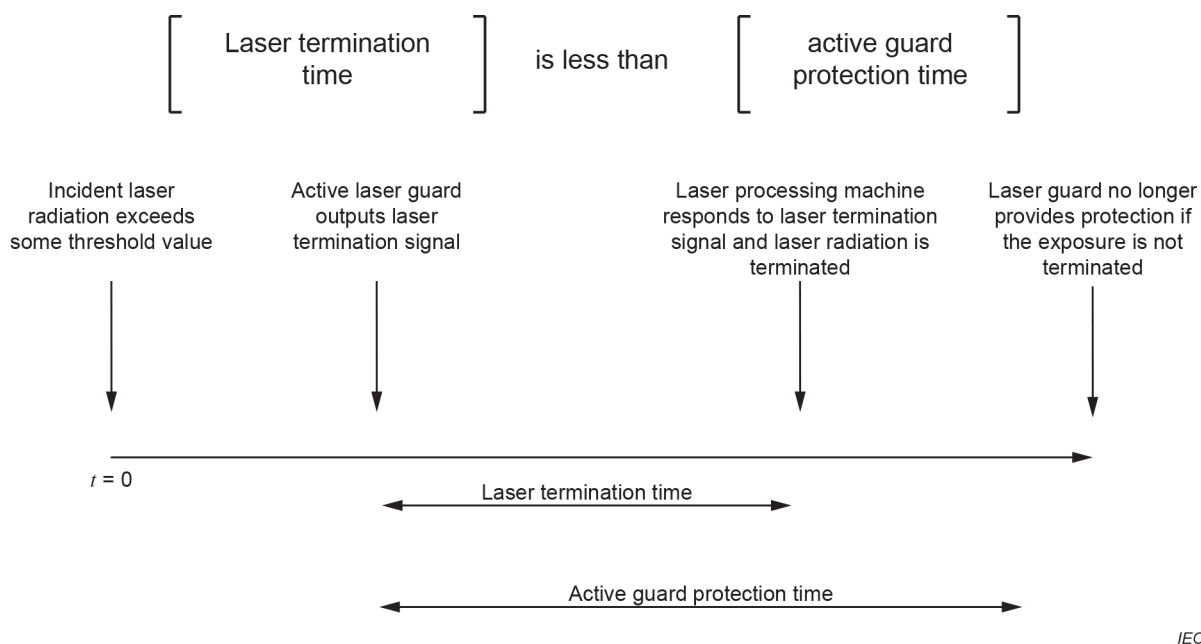


Figure C.2 – Illustration of active laser guard parameters

Annex D (normative)

Proprietary laser guard testing

D.1 General

Annex D contains details of the test conditions to be adhered to and the documentation to be supplied by manufacturers of proprietary laser guards.

It should be noted that it is inappropriate to use higher power lasers to simulate low power laser parameters or use low powered lasers to simulate high ~~powered~~ power laser parameters, by changing irradiance or by adjustment of the distance from the focal point, because beam quality and other characteristics of the laser beam are likely to be different or unexpected. Manipulating characteristics of lasers of a certain power level to make or extrapolate estimates of a laser ~~in~~ of a different level (higher or lower power) is not permitted.

The evidence of the tests described herein is relevant only for, and is limited to, the laser parameters used. Thus the results of these tests should serve only for comparison of laser guards.

The protective exposure limit (PEL W m^{-2}) shall be applicable only for the beam dimensions at the guard used in the tests. These dimensions at the guard shall be stated by the laser guard manufacturer because the PEL, which indicates protection, decreases as the laser beam dimensions increase. If the PEL is exceeded, the guard can be damaged and eventually disintegrates. For the purposes of Annex D, the protection time is the time interval from initial irradiation of the front surface until the laser radiation emitting beyond the rear surface exceeds the accessible emission limit (AEL) for Class 1 as defined in IEC 60825-1.

For power levels greater than 4 kW and for BPP less than 4 mm·mrad, the absorbed power density often does not increase linearly. It is, however, suggested that the experimental procedure described in Annex D is followed to determine the protection time for the desired PEL when the output from a combination of laser, optics and fibre optics is in excess of 4 kW.

Care should be exercised even at lower powers when interpreting results as the occurrence of non-linear effects cannot be excluded or ignored. Tests should be undertaken using an optical setup that corresponds to the overall laser system for which the guards are intended to be used.

D.2 Test conditions

D.2.1 General precautions for test conditions

A variety of exposure limit tests with different materials and different lasers may cause non-reproducible results that can lead to false interpretations for the protective exposure limit and overestimated lifetime predictions of laser guards. Thus equal and comparable conditions for repeated tests ~~must~~ shall be ensured to maintain the integrity of the results.

As part of ensuring the integrity of the results, effort shall be made to eliminate or at least minimize systematic or other errors that may also result in false interpretations for the PEL or overestimation of the guard lifetime. Such errors may arise from:

- a) material: reflecting surfaces, where reflectivity changes through oxidation or contamination;
- b) laser: with high power lasers (e.g. multi-kilowatt lasers), especially those with good beam quality (i.e. fibre lasers and disk lasers), reactions have been seen that have considerable influence on the actual irradiance on the surface of the laser guards.

Thus during testing, ~~it is important that~~ no mechanical or physical effects (such as described below) shall occur between the beam aperture and the point of incidence on the guard material that adversely affect any optical properties. ~~It is important to note that~~ Testing conditions ~~should~~ shall be accurately replicated, otherwise the resultant ~~PEL or~~ passive guard protection times may not be reliably reproduced.

Examples of effects that influence test results include but are not limited to:

- generation of fine metallic fume, whereby laser radiation is absorbed (e.g. thermal blooming) or scattered (e.g. Mie effect) in the metallic fume;
- change of the focal point (thermal induced focal shift), whereby there is a change of the power density at the surface of the laser guard. These effects may reduce the laser power on the sample under test;
- establishment of an equilibrium (i.e. thermal equilibrium or balance between incident and reflected or reemitted radiation) leading to a practically infinite ~~PEL or~~ passive guard protection time in one test, while a repeated test under assumed equal conditions leads to a finite PEL or protection time.

The tested exposure limit (W m^{-2} for CW lasers or J m^{-2} for pulsed lasers) shall be determined by tests performed when irradiating at least ~~six~~ ten samples by irradiating one surface of each sample. Each sample shall be of representative thickness, composition and surface finish, having a front test surface prepared to give worst case absorption to laser radiation. Dimensions of these samples shall be not less than three times the beam diameter measured at the points where the intensity distribution has decreased to a value of $1/e^2$ of the peak at the exposure location (thereby guaranteeing that the radiant heat flow is taken into account). Structural connecting elements shall only be included in the tests if they are necessary to ensure the construction and integrity of the guard. In the case of non-circular beams, the geometry of the beam used in the test shall be specified. Non-circular beams are those where the difference between the major and the minor dimension is greater than 10 %. The tests shall be performed in both pulsed and CW mode where pulsed and CW laser operation is possible as the pulsed radiation may lead to different results.

NOTE 1—The parameters of pulsed radiation used in these tests should be representative of the parameters to be used in any specified application.

NOTE 2—The geometry of the test beam is required to be specified because it affects the distribution of heat in the sample.

NOTE 3—Particular care should be taken in the preparation of samples when testing laser guards using aluminium, copper, stainless steel and materials with zinc coated surfaces. It has been observed for these and other similar materials, that the PEL and protection time ~~is~~ are highly dependent on sample preparation and experimental setup that affects the repeatability of the PEL and protection time measurements.

NOTE 4—The worst case absorption should take into account the reflectivity of the guard material and the changes to the surface of the laser guard material over the foreseeable lifetime of the laser guard. However, the test plate should not have been treated beforehand, in any possible way that could alter absorption conditions artificially, except for accelerated natural reflectivity change of the guard material and the accelerated natural changes to the surface of the laser guard material reasonably expected over the foreseeable lifetime of the laser guard. Qualification test should be done in normal conditions for the laser shielding.

If a sample holder is necessary for the tests, then its maximum overlap on the sample edge shall not exceed 3 mm from the edge of the sample. The holding arrangement in contact with the sample shall be thermally insulating (e.g. ceramic, ~~etc.~~), compatible with use at the temperatures generated.

The sample shall be normal (or tilted no more than $\pm 3^\circ$ to avoid retro-reflections) to the laser beam with the beam axis centred on the sample at a distance F_1 as shown in Figure D.1. The distance F_1 past the focal point shall be not greater than three times the focal length (F) of the focusing lens. If for a specific application the guard is to be positioned at a distance less than three times the focal length (F) away from the focal point, the minimum distance between the focal point and the guard ~~has to~~ shall be taken as the distance F_1 .

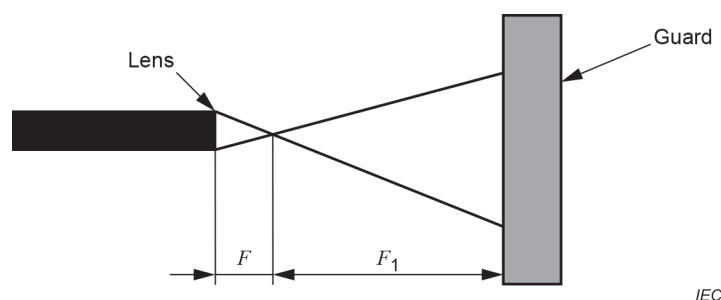


Figure D.1 – Simplified diagram of the test arrangement

NOTE 5—Test should be performed with horizontally directed beam as shown in Figure D.1. If a different beam direction were used, mention the test arrangement regarding the beam direction in the qualification report.

The surface of the sample under test shall be sufficiently ventilated (e.g. by using a cross jet) to ensure that the test surface and the space between the test sample and the beam shaping optics remain clear of debris, fume, etc. during the period of the test. The ventilation shall have the same effect as the air circulation in the intended application.

In addition, where there are multiple layers to the sample guard, all internal surfaces and internal spaces shall be sufficiently ventilated (e.g. by using a cross jet, [see Figure D.2](#)) to ensure that all surfaces remain clear of debris, fume, etc. during the period of the test.

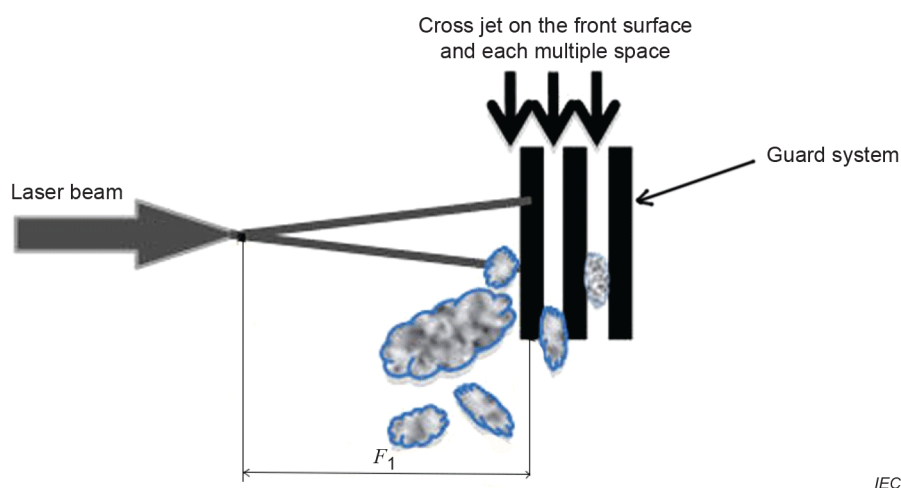


Figure D.2 – Simplified diagram of the ventilation for the guard under test

D.2.2 Laser guard test conditions for passive laser guards

For passive laser guards: the accessible laser radiation at the rear surface of the sample shall not exceed Class 1 AEL during the test exposure, the duration of which is dependent on the period of exposure set by the manufacturer of the proprietary guard. The protection time of the guard ~~must~~ shall exceed the maintenance inspection interval as defined in Table D.1 subject to the intended laser guard usage.

Maintenance inspection intervals of proprietary laser guards should be specified by their manufacturer using test classifications T1, T2 or T3 as defined in Table D.1. Maintenance inspection intervals represent the time interval after which the guard is completely inspected and verified as not damaged or deteriorated. This is to ensure that the guard is in a state that can tolerate exposure to laser radiation for a further maintenance interval.

Table D.1 – Laser guard test classification

Test classification	Maintenance inspection intervals	Suggested laser guard usage
T1	30 000	For automated machine usage
T2	100	For short cycle operation and intermittent inspection
T3	10	For continuous inspection by observation

D.2.3 Requirements for active guards

For active guards the following ~~shall be required~~ requirements apply.

- If the active guard is a part of a safety-related control system of a machine, the relevant and appropriate standard for safety-related control systems shall be applied.
- The active laser guard shall output the laser termination signal (which is intended to lead to automatic termination of the laser radiation), in response to any exposure of its front surface to laser radiation in excess of the specified exposure (level and duration). A reasonably foreseeable fault within the active guard system shall not lead to the loss of the safety function. A reasonably foreseeable fault within the guard element shall be detected at or before the next demand upon the safety function.
- The accessible laser radiation at the rear surface of a sample of the passive laser guard, incorporated in the active laser guard, shall not exceed Class 1 AEL in response to any exposure of its front surface to laser radiation up to and including the specified exposure for an exposure duration greater than the specified active guard protection time (as defined in 3.2).
- If automatic functionality checks within the active guard system are made during periods of laser emission that temporarily interrupt the operation of the active laser guard system, the accumulated time taken to complete these checks shall take into account the effect of any repetitive laser pulses and shall not exceed the active guard protection time or cause any reduction in the overall performance of the active laser guard.
- The operation of an active guard is dependent on changes of physical parameters causing the initiation of the active guard termination signal. The active guard shall be continuously monitored during the period of potential laser exposure. At other periods, the active guard shall be unaffected by parameter changes (for example, smoke, humidity, vibration or shocks, temperature changes) and any other changes in the environment, thus preventing the active guard from being inadvertently disabled.
- Any damage to the active guard shall be detected at or before the next demand for protection and until that damage has been rectified, further operation shall be prevented.

D.3 Protection time corresponding to the specified protective exposure limit (PEL)

The passive guard protection time corresponding to the specified protective exposure limit (PEL) (as defined in 3.21 ~~or protection time~~) shall be determined from the results obtained from the measurements made. Experimental irradiating laser power density shall be adjusted to be greater than or equal to the specified protective exposure limit (PEL). When calculating the protection time from the sampled data, the central limit theorem shall be applied presuming an underlying normal distribution.

Individual samples tested in the batch that do not burn through during the test shall be statistically disregarded unless the entire batch does not burn through.

A confidence level of 99 % is required and is ensured by using $\pm 3\sigma$, where σ is the standard deviation in the normal distribution as given by

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

where

$p(x)$ is the probability of x ;

x is the individual value of a sample; and

μ is the mean of experimental burn-through time of the tested samples, except for laser guards made of pitch-type CFRP (carbon fibre reinforced polymer) and similar materials. For laser guards made of pitch-type CFRP, μ shall be defined as the mean of the experimental rear-side ignition time, if it is shorter than the mean of experimental burn-through time.

If the arithmetic value of the mean of measured burn-through times for the tested samples minus 3σ is a negative number, the value shall be made to equal zero.

NOTE 1 In these tests especially for materials with reflective surfaces and/or a low melting point (for example, aluminium), the non-linear effects can result in a negative value for 3σ . These non-linear effects can also erroneously indicate a shorter distance between the focus and the surface of the sample primarily due to the reflecting (or mirror) properties of the sample material.

The quoted PEL for the passive protection time shall be ~~equal to $0,7 \times$ tested exposure limit~~ the laser power density actually used in the passive protection time measurement test or shall be determined between two measurement points.

The protection time shall be equal to $0,7 \times (\mu - 3\sigma)$ s.

NOTE 2 The factor 0,7 referred to in the equation for PEL ~~or~~ and protection time is introduced as an additional safety factor.

NOTE 3 The samples are randomly selected from a basic population.

D.4 Information supplied by the manufacturer

The manufacturer shall provide with the set of test sample data at least the following information:

- name and address of the organization conducting the tests;
- the number of this document (IEC 60825-4);
- the material and its specification or internationally recognized standard to which it is made or rated, used for the samples. Details of any heat treatment, work hardening, surface finishes or other process applied to the material shall be included in this specification.

- d) the number of samples used in the tests;
- e) details of the laser parameters used including at least
 - 1) the laser wavelength(s),
 - 2) the power or energy (specifying peak or average) at which testing was conducted,
 - 3) the pulse duration and repetition rate (for tests using a pulsed laser),
 - 4) the beam diameter ($1/e^2$) at the input of the focal lens,
 - 5) ~~the beam quality expressed appropriately, for example,~~ the beam parameter product ~~or~~ M^2 (mm·mrad),
 - 6) the beam cross-sectional shape at the focus, and
 - 7) a measurement of the radiant exposure or irradiance of the beam at the surface under test;
- f) focal length of the focus lens used in the tests;
- g) the distance F_1 ;
- h) the maintenance inspection interval applicable to the laser guard;
- i) the resultant ~~PEL and/or~~ protection times and PEL together with any calculations and statistical analyses made.

Annex E (informative)

Guidelines on the arrangement and installation of laser guards

E.1 Overview

Annex E addresses the arrangement and installation of guards to protect personnel against laser radiation hazards around the process zone of a laser materials processing machine. These guidelines are for use by manufacturers and/or users. The object of Annex E is to encompass guarding for a stand-alone laser-processing machine (see ISO 11553-1-⁴) and additional (often user-installed) guarding required to safely integrate a laser-processing machine. Guarding issues relating to associated hazards of laser processing (which include mechanical, electrical, fume and secondary radiation hazards) are not considered in detail in Annex E.

E.2 General

E.2.1 ~~Introduction~~ Requirement

Laser guarding is required to isolate the laser hazard in addition to the associated hazards of laser processing. Some of the guards may form part of a laser-processing machine, additional guarding may be used to facilitate safe loading and unloading of workpieces, and for servicing.

E.2.2 Arrangement of guards

Key elements in assessing the arrangement and installation of guards around the process zone include:

- a) the degree of accessibility required for workpiece handling (especially the degree of manual manipulation);
- b) the method of fixing the workpiece (e.g. use of jigs and clamps);
- c) the method of removal of the workpiece and any associated parts (e.g. scrap) after processing.

E.2.3 Location of guards

Good practice in determining the location of laser guards includes:

- a) ~~when possible~~, the laser guard should be located at least three focal lengths away from the focal point of a focusing lens;
- b) laser guards with lower protective exposure limits (PELs), for example viewing windows, should not be located where the direct beam or specular reflections are expected.

E.2.4 Complete enclosure

A complete enclosure is one which meets all the requirements for a protective housing as specified in 6.2.1 of IEC 60825-1:2014 and encompasses the embedded laser and the entire process zone, such that there is no human access to hazardous radiation.

E.2.5 Incomplete enclosure

An incomplete enclosure is one which does not provide a complete protective housing encompassing the embedded laser and the entire process zone, such that human access to hazardous radiation is possible.

⁴⁾ ~~Also published by the European Committee for Standardization as EN 12626.~~

If the risk of exposure is not tolerable (to those who may be on walkways or platforms which raise them above the guards of an open topped machine), additional control measures are required.

E.2.6 Hierarchy of control of laser hazard areas

The following hierarchy of measures is recommended for keeping persons out of an area where there is an intolerable risk:

- a) fit a fixed guard;
- b) fit a removable guard;
- c) fit an electronic protection device linked to the safety interlock chain of the machine, around the perimeter of the area (e.g. a light beam sensor) or over the area (e.g. a pressure-sensitive mat);
- d) provide a physical barrier plus information, instruction, training, supervision;
- e) provide a means of allowing use with the operator some distance from the process zone plus personal protective equipment (PPE).

NOTE Measures (c) and (d) provide no protection from laser radiation emerging from the laser machine and ~~should~~ **can** therefore only be considered where the distance of the controlled boundary from openings in the machine exceeds the nominal ocular hazard distance (NOHD).

E.2.7 Personal protective equipment

Personal protective equipment should only be used as a last resort where a combination of engineering and administrative controls cannot reasonably provide a sufficient level of protection. Where personal protective equipment is employed it should be supported with an adequate level of administrative control governing its use. It should only be used when a risk assessment has shown that the use of other means of risk reduction has failed to produce a sufficient degree of safety and when it is not reasonably practicable to ensure adequate protection by other means. When working with Ultraviolet B (290 nm to 320 nm) and Ultraviolet C (100 nm to 290 nm) protective clothing may be required.

E.2.8 Human intervention

Where machine operations require human access, then human intervention can be included in the risk assessment and the consideration of implications for the duration of the fault condition. Under these conditions, access should be controlled and accessible only to authorized persons who have received adequate training in laser safety and servicing of the laser system involved. The area should also be restricted and not open to the public and where observers or other untrained personnel are kept from being exposed to the hazards by barriers or administrative controls.

E.3 Risk assessment

E.3.1 ~~Introduction~~ Requirement

Human exposure to a laser beam of the type typically used in laser materials processing can produce a moderate to severe injury, depending on laser wavelength, tissue exposed and the response of the victim. The probability of such an exposure occurring becomes the key variable element in assessing the risk of injury. The reduction of risk to tolerable levels is an iterative process. There is no standard approach to procedure and documentation for this process. Nevertheless, the steps involved are universal and are described in ISO ~~44124~~ 12100.

E.3.2 General considerations

E.3.2.1 Risk assessment considerations

A risk assessment should be performed to identify hazardous situations and to assess the foreseeable exposure level on intended positions of a laser guard. This assessment should take into account a number of factors, including those described in E.3.2.2 to E.3.2.14.

E.3.2.2 Features of the laser process zone

Relevant features include the laser power and wavelength, the focal length of optics, and the degrees of freedom of the beam delivery (e.g. number of axes of movement).

E.3.2.3 Process

The nature of the process, such as cutting, drilling, welding, marking. The machine may be dedicated or offer several processes.

NOTE Reflected laser powers differ appreciably with process and material being processed.

E.3.2.4 Process control

This factor addresses in particular the time during which laser guards may be exposed under fault conditions, including those upon which the foreseeable exposure limit (FEL) is determined (e.g. the process cycle time), the inspection process (e.g. per item or per time period ~~or~~ per number of items), and the means and effectiveness of automatic process control intervention in the event of a fault condition becoming evident.

E.3.2.5 Manual operations

Operator intervention considerations include the need and provision for manual control, the means and effectiveness of process observation (including the location of viewing windows or cameras) and the accessibility and effectiveness of intervention in the event of a fault condition becoming evident.

E.3.2.6 Robot operations

The full range of robot movements, impact protection for the robot head and general protection of service lines and the beam delivery to the robot, and the means of limiting robot head movement and direction (e.g. software limits, hardware limits and physical limits), in particular the closest approach of the exposed laser beam to laser guards.

E.3.2.7 Workpiece

The geometry, composition and surface finish of the workpiece, and how it can affect the direction and strength of reflections during laser processing.

E.3.2.8 Clamping and fixturing

The holding and positioning of the workpiece and the related issues of reflections from surfaces and collisions of the focusing head.

E.3.2.9 Loading and unloading

The method by which the workpiece is introduced and removed, in particular whether it is manual or automatic, single piece or continuous, and the method (e.g. sliding, rolling or lifting door) and control of access to the process zone.

E.3.2.10 Beam delivery

Beam delivery considerations include the optical method (mirror or fibre) and means of inspection, positioning and movement of optical components. Considerations include the structural integrity of the mounting of beam path components, means of maintaining the condition of optical components (e.g. clean dry gas purge plus cooling supply), means of maintenance of beam alignment, provision of on-line errant and non-errant beam monitoring, and means of construction of the beam delivery enclosure.

NOTE Particular attention ~~should~~ can be given to the use of novel (unproven) design of laser beam delivery, the exposure of the beam delivery structure to external mechanical forces (e.g. vibration) which ~~may~~ can give rise to optical misalignment. Attention ~~should~~ can also be given to tampering with optics or anomalous performance of lasers, especially in regard to beam pointing, and situations where the laser power is so high that the performance of beam delivery optics is uncertain.

E.3.2.11 Location of workers

The defined work area, in particular the minimum distance of permitted approach to the machine. Included in this consideration are overhead locations (e.g. crane operators, office workers on elevated walkways), steps and ladders in the vicinity.

E.3.2.12 Maintenance provision

This consideration includes the means and control of access to maintenance positions (e.g. removable panels, key control) and the provision of interlock overrides and emergency stops.

E.3.2.13 Guarding properties

The assessment of FEL and PEL under normal conditions and reasonably foreseeable fault conditions should be made for each element of guarding, including fixed and moveable walls and windows.

E.3.2.14 Guarding environment

Environmental factors that may influence the effectiveness of the guarding, including access for fork lift trucks and other moving objects that could cause significant mechanical damage and dusty environments that could adversely affect the performance of optics and/or the protective properties of the guard.

E.4 Examples of risk assessment

E.4.1 Continuous feed of components

a) Example.

Laser processing unit mounted over a conveyor belt.

b) Location.

During normal production or maintenance, access is controlled and only accessible to authorized persons, but the area may also be unrestricted and open to observers or other untrained personnel.

During service periods, the area may also be restricted and not open to other untrained personnel.

c) Key issue.

The arrangement of laser guarding should include entry and exit ports to permit the feeding of components into and out of the process zone on a continuous basis.

d) Possible solutions.

1) Where the risks of excessive laser radiation are high:

- provide interlocked sliding guard, which opens to permit entry of the component, and closes prior to laser processing.

2) Where the risks of excessive laser radiation are medium or low (possible solutions following the risk assessment):

- provide local guarding with a brush seal to maintain enclosure during passage of component, or
- provide an open tunnel around opening(s) to restrict line-of-sight access to the laser process zone. This may be accomplished by:
 - using a labyrinth for the component entry and exit paths in order to block direct line of sight, or
 - by the use of an interlocked barrier (e.g. light guard or fencing) or a pressure-sensitive mat that is approved for safety applications, to restrict the viewing position in order to prevent a direct line of sight.

E.4.2 Flatbed laser cutting and marking

a) Example.

Flatbed cutting table in laser job-shop environment.

b) Location.

During normal production or maintenance and service periods, access is controlled and only accessible to authorized persons and restricted to trained personnel only.

c) Key issues.

Access to the table is required for loading and unloading of sheets onto the cutting table.

d) Possible solutions.

1) Where the risks of excessive laser radiation are high (for example where hazardous laser radiation is generated from reflections which are present during normal production):

- provide full perimeter guarding to protect the operator and other personnel. Interlocked sliding guard opens to permit passage of component and closes prior to laser processing.

2) Where the risks of excessive laser radiation are medium or low (for example beam is directed vertically onto a flat workpiece and enclosed to within a short distance of the workpiece):

- provide free-standing guard to protect the laser operator;
- provide PPE requirement for all persons within the restricted access zone.

In all cases, provide adequate controls to ensure unauthorized and untrained persons are prevented from exposure to any hazard that may cause harm.

E.4.3 Multi-axis processing machine

a) Example.

Automated robotic laser welder on an automobile line.

b) Location.

During normal production or maintenance, access is uncontrolled and the area is unrestricted and open to observers or other untrained personnel.

During service periods, access would be controlled and only accessible to authorized persons and the area restricted and not open to other untrained personnel.

c) Key issue.

A fault condition in the controller could lead to the laser beam being directed at the laser guarding.

d) Possible solutions.

1) Where the risks of excessive laser radiation are high:

- provide reinforced guarding at parts of process zone enclosure indicated as vulnerable by the risk assessment. This reinforcement may be by using an active guard.

2) Where the risks of excessive laser radiation are medium or low:

- the elements of solution may include:
 - provide guarding which has a verified performance being tested as described in this document for direct exposure to representative laser beam;
 - provide software control and hardwire limits to beam-line rotational movement;
 - provide collision protection of the beam-line 'head';
 - provide additional sensors for preventing laser emission beyond the workpiece;
 - provide control of the laser emission if the laser focusing head is stationary.

E.4.4 Laser guards for supervised areas

a) Example.

Temporary laser guards set up during service activities to exclude persons not involved in the servicing operation.

b) Location.

During normal production or maintenance, these laser guards would not be used as a protective guard.

During service periods, access would be controlled. The location is only accessible to authorized persons who are trained in laser safety. The location is not open to other untrained personnel as indicated by administrative means (e.g. warning signs).

c) Key issue.

Beam direction is under administrative control.

d) Possible solutions.

1) Where the risks of excessive laser radiation are high, the elements of solution include:

- ensure laser guards are opaque and are capable of at least 100 s protection from the laser beam;
- entry to the screened off area interlocked or under direct administrative control;
- use trained personnel to carry out such service operations;
- protective laser eye wear (and possibly skin wear) to be used by all those inside the controlled area.

2) Where the risks of excessive laser radiation are medium or low (e.g. area outside the laser guard is cleared of personnel):

- as above, except that the protection time provided by the screen may be less than 100 s provided the service engineer has ready access to the laser shutter control and laser exposure of the screen provides a clearly visible indication (e.g. smoke or strong discoloration).

E.5 Aids to risk assessment

E.5.1 Considerations to be taken into account

Clause E.5 provides a list of items to be considered when assessing the risks associated with a laser-processing machine in the design of laser guards. These details should form part of a documented record of the assessment.

Note that this list is not comprehensive and may not include all the aspects that should be considered.

E.5.2 Equipment

- a) Laser:
 - 1) type;
 - 2) wavelength;
 - 3) CW/pulse;
 - 4) pulse duration;
 - ~~Pulse repetition rate~~
 - 5) power (or energy);
 - 6) beam delivery output lens focal length.
- b) Processing machine type:
 - 1) two-axis machine;
 - 2) three-axis machine;
 - 3) machine with more than three axes;
 - 4) robot;
 - 5) fume extraction fitted;
 - 6) process zone enclosure:
 - Class 1 AEL;
 - other.

E.5.3 Process machine beam delivery

- a) Beam delivery path monitoring:
 - 1) by hardware control;
 - 2) by software control.
- b) Beam delivery turning mirror monitoring:
 - 1) by hardware control;
 - 2) by software control.
- c) Beam delivery mechanical assembly:
 - 1) requires use of tools;
 - 2) monitoring provided:
 - by hardware control;
 - by software control;
 - 3) beam focus lens control assembly.
- d) Free space beam delivery system.
- e) Fibre optical beam delivery system.

E.5.4 Process description

- a) Soldering/brazing.
- b) Heat treatment.
- c) Marking.
- d) Welding.
- e) Drilling/cutting.
- f) Cleaning.
- g) Forming.
- h) Rapid prototyping.

E.5.5 Process machine controls

- a) For automatic mode operation (i.e. no operator intervention):
 - 1) fully guarded operation.
- b) For manual mode operation (i.e. where manual intervention during the machine cycle is intended):
 - 1) fully guarded operation.
- c) Method of process observation:
 - 1) use of windows in the process zone enclosure;
 - 2) use of CCTV monitoring;
 - 3) other;
- d) Method intended to stop the cycle if an error observed
 - 1) emergency stop;
 - 2) normal stop.

E.5.6 Basic description of robot (see ISO 10218-1)

- a) Swing range:
 - 1) restricted space;
 - 2) maximum space;
 - 3) safeguarded space.
- b) Method of limiting range of motion:
 - 1) hardware control;
 - 2) software control.
- c) Method of safeguarded space interlocking:
 - 1) hardware control;
 - 2) software control.
- d) Collision sensing:
 - 1) hardware control;
 - 2) software control.
- e) End position control:
 - 1) hardware control;
 - 2) software control.

E.5.7 Types of processed parts

- a) Type of geometry:
 - 1) plate;
 - 2) other.
- b) Type of material.

E.5.8 Part fixture

- a) Automatic location and clamping:
 - 1) by hardware control;
 - 2) by software control.
- b) Manual location and clamping.
- c) Laser beam damage potential:
 - 1) due to reflective areas on the tooling;
 - 2) due to surface finish of the tooling.

E.5.9 Material flow into the process zone

- a) Automated continuous flow of components.
- b) Manual single component.
- c) Process zone component access:
 - 1) sliding door;
 - 2) lift door;
 - 3) rolling door;
 - 4) tunnel;
 - 5) other.
- d) Component feed control:
 - 1) by hardware control;
 - 2) by software control;
 - 3) process zone guarding designed to requirements of this document;
 - 4) process zone enclosure tested to requirements of this document.

E.5.10 Process machine operator

- a) Working area.
- b) Inside machine.
- c) Outside machine.

E.5.11 Maintenance

- a) Position of maintenance access doors.
- b) Method of machine authorization (key controls).
- c) Hold-to-run controls.

Annex F (informative)

Guideline for assessing the suitability of laser guards

F.1 Identification of hazards

~~F.1.1~~ Selection of safety measures

When applying the strategy for selection it may not be possible to use the more effective types of safety measures because they are either not technically feasible or are not suitable for their particular application.

In considering measures for all the hazards during each relevant phase of machine life, risk assessment techniques will assist in choosing the best possible combination of safety measures.

The phases of machine life to be considered are:

- a) installation;
- b) commission;
- c) operation;
- d) setting or process changing;
- e) cleaning;
- f) adjustment;
- g) maintenance;
- h) service.

There may be conflicting requirements and priority should be given to those phases which give rise to the greatest risk. For example, the maintenance, setting and adjustment phases may require to be given greater emphasis. The aim is to minimize total risk.

F.2 Risk assessment and integrity

~~F.2.1~~ General Hazards to be identified

As with other machinery, all mechanical hazards should be identified.

These hazards include:

- a) entanglement;
- b) friction and abrasion;
- c) cutting;
- d) shear;
- e) stabbing and puncture;
- f) impact;
- g) crushing;
- h) drawing in;
- i) injury by compressed gas or a high-pressure fluid system.

Non-mechanical hazards may also be present.

These hazards include:

- a) access:
 - 1) slips, trips and falls;
 - 2) falling objects and projections;
 - 3) obstructions and projections;
- b) handling and lifting;
- c) electricity (including static electricity):
 - 1) shock;
 - 2) burns;
- d) chemicals that are:
 - 1) toxic;
 - 2) irritant;
 - 3) flammable;
 - 4) corrosive;
 - 5) explosive;
- e) fire and explosion;
- f) noise and vibration;
- g) pressure and vacuum;
- h) temperatures (high and low);
- i) inhalation of mist, fume and dust;
- j) suffocation;
- k) ionizing and non-ionizing radiation;
- l) biological, e.g. viral or bacterial.

Many of the safeguards, which are adopted in order to eliminate personal harm from non-mechanical hazards, will need to be considered in conjunction with the safeguarding against the mechanical hazards identified in order to minimize the total risk level.

F.2.2 Guard reliability

The greater the risk, the greater is the need to protect against it. The reliability of the safety measure should increase as the probability or severity of injury resulting from failure of the measure increases. This applies to safeguards and controls in general, to interlocks and to guard materials.

The identification of the various hazards should be followed by a careful study of the possible failures or combinations of failures which might lead to these hazards causing injury. In any system where a failure may adversely affect safety, each component within the system should be considered in turn. The likely types of failure and their consequences for the system as a whole should be taken into account. A formal method of analysis, such as Failure Modes and Effects Criticality Analysis (FMECA) should be used when higher risks are involved. It is also necessary to consider the reliability of operating procedures when safety depends upon them. This should include both inadvertent and deliberate failure to follow procedures.

Guards should achieve their safety function with minimal downtime and the least reduction in productivity. It should be recognized that production pressures or well-intended zeal could lead to safeguards being defeated. Designers should design and construct safeguards to make bypassing or defeating them, whether deliberately or by accident, as difficult as is reasonably possible.

Annex F only considers the features of guards that directly relate to giving protection from excessive exposure to laser radiation.

A number of special hazards should be considered associated with:

- a) the type of machine;
- b) the wavelength(s) of laser radiation;
- c) number of axes of movement of the machine;
- d) complexity of beam path.

F.2.3 Practical risk assessment methods

F.2.3.1 Generalized risk assessment methods

These methods are outlined in Annex E.

F.2.3.2 Risk assessment as suggested in ISO 13849-1

ISO 13849-1 deals with those parts of machinery control systems assigned to provide safety functions. These parts can consist of hardware or software and they provide the safety functions of the control system. They can be separate or integrated parts of the control system. The performance of a safety related part of a control system with respect to the occurrence of faults is allocated in ISO 13849-1 into five categories (B, 1, 2, 3, 4) which should be used as reference points.

The category selected, as defined in ISO 13849-1, will depend upon the machine and the extent to which control means are used for the protective measures.

When selecting a category and designing a safety-related part of a control system, the designer will need to declare at least the following information about the safety-related part:

- a) the category or categories selected;
- b) the functional characteristics;
- c) the precise role the safety-related control plays in the machinery protective measure(s);
- d) the exact limits of the safety-related control;
- e) all safety-relevant faults considered;
- f) those safety-relevant faults not considered by fault exclusion and the measures employed to allow their exclusion;
- g) the parameters relevant to the reliability, such as environmental conditions;
- h) the technology or technologies used.

The use of the categories as reference points and the declaration of rationale followed during the design process are intended to allow ISO 13849-1 to be used with flexibility. ISO 13849-1 provides a clear basis upon which the design and performance of any application of the safety-related part of the control system (and the machine) can be assessed.

The main body of ISO 13849-1 describes the process for selection and design of the safety measures together with the characteristics of the safety functions and the fault considerations.

Annex B of ISO 13849-1:2015 is particularly useful in providing guidance on the selection of categories including a method for risk estimation.

F.2.3.3 ALARP

This method is intended to reduce risks to "as low as reasonably practicable" (ALARP) by means of a structured approach to design and implementation. The main tool is to use good practice. In this context, good practice is the generic term for those procedures for controlling risk. Written good practice may take many forms. The scope and detail of good practice will reflect the nature of the hazards and risks, the complexity of the activity or process and the nature of the relevant legal requirements. Examples of written sources which may be recognized include guidance produced by government departments, standards produced by standards-development organizations (e.g. CEN, CENELEC, ISO, IEC) and guidance agreed by a body (e.g. trade federation, professional institution) representing an industrial/occupational sector.

Table F.1 shows how ALARP could be applied.

Table F.1 – Application of ALARP

Project stage	Elements in demonstrating that risks are as low as reasonably practicable
Choosing between options or concepts	Risk assessment and management in accordance with good design principles. Demonstrating that duty-holder's design safety principles meet legal requirements. Demonstrating that chosen option is the lowest risk or justification, if not the lowest risk. Comparison of option with best practice, and confirmation that residual risks are no greater than the best of existing installations for comparable functions. Risk considered over life of facility and all affected groups considered. Societal concerns met, if required to consider.
Detailed design	Risk assessment and management in accordance with good design principles. Risk considered over life of facility and all affected groups considered. Use of appropriate standards, codes, good practice, etc. and any deviations justified. Identification of practicable risk reduction measures and their implementation unless demonstrated not reasonably practicable.

F.3 General design

Designers of new machinery, where considering safety, should follow the general principles laid down in ISO 12100-1 and ISO 12100-2, also taking into account any other specialized standards that relate to the particular machine. As a practical guide whenever practicable, hazard zones should be eliminated or effectively enclosed. If they cannot be eliminated, then suitable safeguarding should be incorporated as part of the design or made easy to incorporate at a later stage.

At the design stage, arrangements should be made, where practicable, to eliminate the need to expose any hazard zones during operation, examination, adjustment and maintenance.

Designers should take into account the ergonomics of the machinery use, i.e. they should consider all aspects of the work situation for which the machine was intended. The objective is to provide for laser safety while giving the optimum performance of the machine and operator.

Among the aspects to consider is the creation of a favourable environment for the operator and others in the vicinity nearby, providing heating, cooling, lighting and, where necessary, mechanical aids to reduce physical effort and controlling to an acceptable level the emission of heat, light, laser radiation, noise, dust, fumes and liquids.

The designer should be aware of the hazards identified above, and as many of these hazards as possible should have been avoided by suitable choice of design features. Where it is not possible to avoid these hazards, the designer should have examined the factors which influence the magnitude of the risk and may influence the severity of the injury. Factors which may influence the frequency of exposure and hence the probability of injury should also have been considered.

Controls should be positioned so as to provide safe and easy operation, and there should be ample clearance between each control and other parts of the machinery. Methods discussed in IEC 60204-1 and IEC 61310-3 should be adopted.

For laser guards particular consideration should be given to:

- a) difficult situations where gaps are necessary;
- b) flaps, skirts and brush seals;
- c) open top enclosures;
- d) jointing between panel sections and window fixings;
- e) improving access (e.g. up and over doors, curtains);
- f) the atmosphere inside enclosures: safe to enter (fume and excess or depletion of oxygen);
- g) viewing windows in enclosures;
- h) secondary (sacrificial) screens;
- i) geometrical and general layout considerations;
- j) design issues relating to type (wavelength) of laser, type of beam manipulation, beam delivery, etc.

F.4 Selection of safeguards

- a) Where access to the danger zone is not required during normal operation of the laser-processing machine, safeguards may be selected for the following:
 - 1) fixed enclosing guards;
 - 2) fixed distance guards;
 - 3) movable guards.
- b) Where persons require access to the danger zone, e.g. for setting, process correction, maintenance or servicing, operational safeguarding may not be fully effective. In these circumstances, safe-working practices such as isolation should be used, augmented where necessary with additional safeguards. The use of such practices will require planning and discipline by all concerned.
- c) Where access to the danger zone is required for normal operation, safeguards may be selected from the following:
 - 1) interlocking guards;
 - 2) adjustable guards;
 - 3) temporary guards.

F.5 Guard design and construction

F.5.1 General requirements for the design and construction of fixed and movable guards

In designing the safeguarding system, the types of guard and the methods of construction should be selected to take into account the mechanical and other hazards involved, in addition to the laser radiation hazard. They should provide the minimum of interference with activities during the operation and other phases of the machine life, in order to reduce any incentive to defeat the safeguard.

Guards should preferably be designed to follow the contours of the machine. Where this is not possible, e.g. for maintenance or because of machine geometry, measures should be taken to reduce the need for presence within the danger zone. Additional safety measures may be required to protect personnel working within the danger zone. These may be provided by safeguards and/or safe working practices.

F.5.2 Fixed enclosing guards

A fixed guard is a guard which is kept closed and in place. Not only should the guard prevent access to hazard zones or laser radiation, it should be of robust construction, sufficient to withstand the stresses of the process and environmental conditions.

If the guard is capable of being opened or removed, this should only be possible with the aid of a tool. Preferably the fastenings should be of the captive type.

When it is necessary for work to be fed through the guard, openings should be sufficient only to allow the passage of material but should not allow the material to get trapped. The guard in these situations should also prevent access to laser radiation, meeting the requirements for the prevention of human access given in IEC 60825-1.

F.5.3 Fixed distance guards

A fixed distance guard is a fixed guard which does not completely enclose the hazard but which reduces access by virtue of its physical dimensions and its distance from the hazard. An example of a distance guard is the perimeter fence surrounding a machine. This type of guard requires extreme care in design if human access to excessive laser radiation is to be prevented. The surrounding guard of an open topped laser processing machine may be considered a fixed distance guard if it is sufficiently high so as to prevent human access to the laser radiation.

F.5.4 Movable and interlocking guards

An interlocking guard is a guard which is movable or has a movable part, and whose movement is interconnected with the power or control of the machine.

An interlocking guard should be so connected to the machine control that:

- a) until the guard is closed the interlock prevents the generation of hazardous laser radiation by interrupting its power source or closing a beam shutter;
- b) either the guard remains locked and closed until the risk of injury from the hazard has passed or opening the guard causes the hazard to be eliminated before access is possible.

Interlocking rise and fall screens, which are capable of inflicting injury in the event of their falling under gravity, should be provided with a suitable anti-fall device. Some interlocking guards may be power driven and, in such cases, adequate steps should be taken to avoid injury due to the movement of the guard.

The interlocking system may be mechanical, electrical, hydraulic or pneumatic or any combination of these. The type and mode of operation of the interlock itself should be considered in relation to the process to which it is applied. The interlocking system should be designed to minimize the risk of failure to danger and should not be easily defeated.

F.5.5 Adjustable guards

An adjustable guard is a fixed or movable guard which is adjusted as a whole or which incorporates an adjustable part or parts. The adjustment remains fixed during a particular operation. It is essential that a suitably trained person carefully carries out the adjustment. Regular maintenance of the fixing arrangement is necessary to ensure that the adjustable element of the guard remains firmly in place once positioned. The guard should be so designed that the adjustable parts cannot easily become detached and mislaid.

F.5.6 Temporary guards

Temporary guards are those that may be positioned during maintenance or service and may be appropriate to supplement overall protection from the laser radiation hazard during the period that permanent guards normally mounted on the processing machine are displaced or removed. Adequate warning signs should be placed on or adjacent to the temporary guards to augment any additional administrative protection measures to ensure the effectiveness of the temporary guards. Procedures should be put in place to ensure that the displaced or removed permanent guards are replaced and the temporary guards removed before the processing machine is returned to normal operation.

F.6 Guard construction and materials

F.6.1 General

Any guard selected should not itself present a hazard such as trapping or shear points, rough or sharp edges or other hazards likely to cause injury.

Guard mounts should be compatible with the strength and duty of the guard.

Power operated guards should be designed and constructed so that a hazard is not created.

ISO 14120 gives general requirements for the construction of fixed and movable guards and should be considered in addition to this document.

F.6.2 Materials

F.6.2.1 General

In selecting the material to be used for the construction of a guard, consideration should be given to the following:

- a) its ability to withstand the forces of any foreseeable hazard associated with the laser processing machine. The guard may fulfil a combination of functions such as the prevention of access and containment of hazards. These hazards include laser radiation, ejected particles, dust, fumes, noise, etc. One or more of these considerations may govern the selection of guard materials;
- b) its weight and size in relation to the need to remove and replace it for routine maintenance;
- c) its compatibility with the material being processed. This is particularly important in the food processing or pharmaceutical industry where the guard material should not cause a source of contamination;
- d) its ability to maintain its physical and mechanical properties after coming into contact with potential contaminants generated or used during processing operations or cleaning or sterilizing substances used during maintenance.

F.6.2.2 Solid sheet metal

Metal has the advantage of strength and rigidity and in solid sheet form is particularly suitable for guarding where adjustments are rarely needed and there is no advantage in being able to see the working operation within the process zone. However, care should be taken to ensure that, where necessary,

- a) sufficient ventilation is provided for the guard to prevent overheating within the process zone, and
- b) the guard does not create a noise or vibration resonance.

Data is shown in Figure F.1 to Figure F.22 that will aid the selection of suitable materials that withstand the foreseeable worst case laser radiation exposures.