

INTERNATIONAL STANDARD



**Safety of laser products –
Part 4: Laser guards**

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**Safety of laser products –
Part 4: Laser guards**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

Part 4: Laser guards

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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.

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- withdrawn,
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- 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.

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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, *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~~

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 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 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,

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

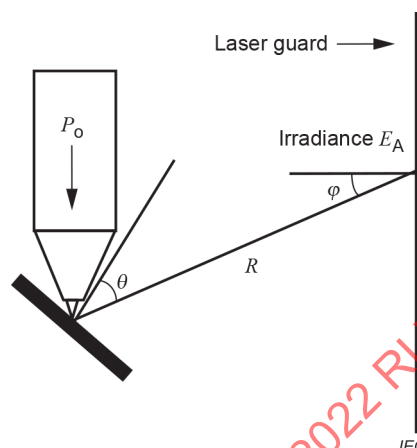


Figure B.1 – Calculation of diffuse reflections

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:

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

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

where ρ is the reflectivity of the workpiece surface.

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

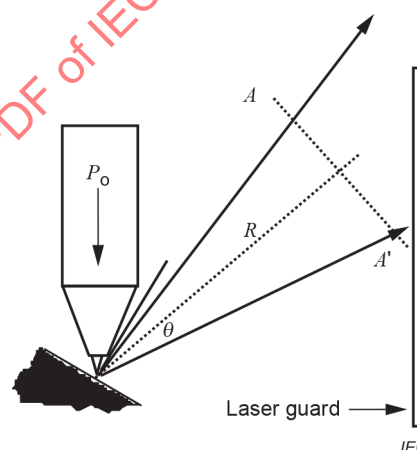


Figure B.2 – Calculation of specular reflections

B.3 Examples of assessment conditions

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

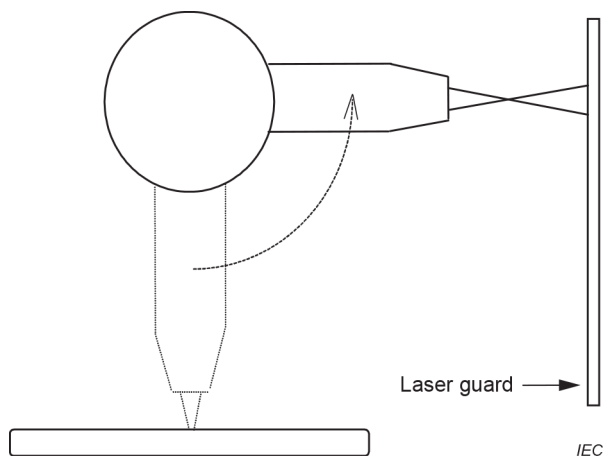


Figure B.3a – Software failure

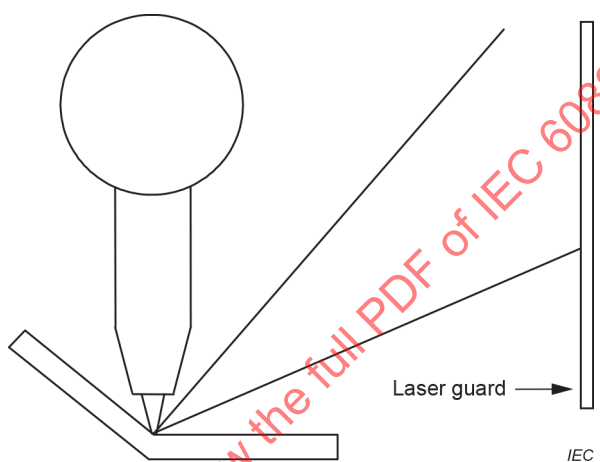


Figure B.3b – Workpiece bends or is inadequately clamped

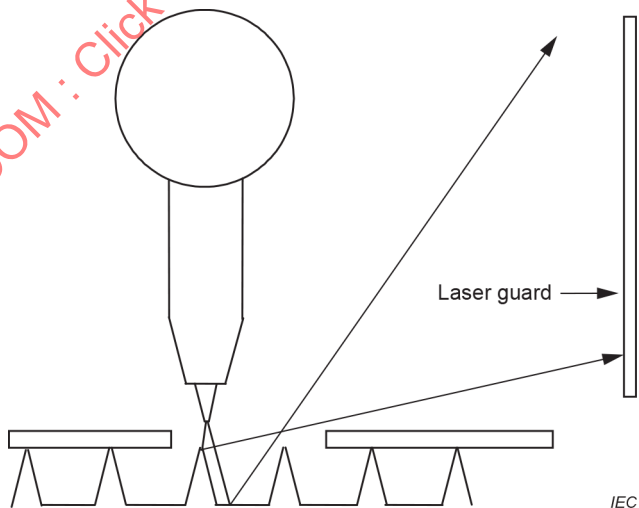


Figure B.3c – Workpiece missing

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

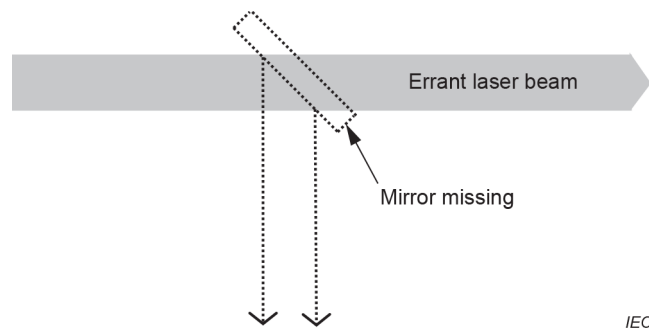


Figure B.4a – Laser is operated with turning mirror missing

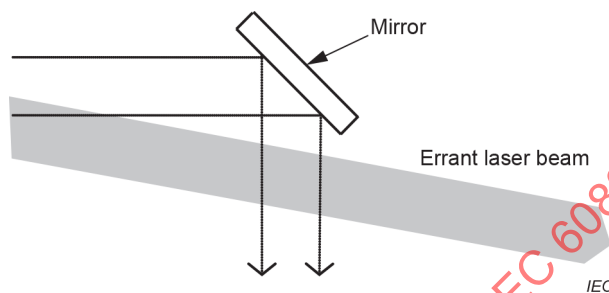


Figure B.4b – Beam displaced off mirror during alignment procedure

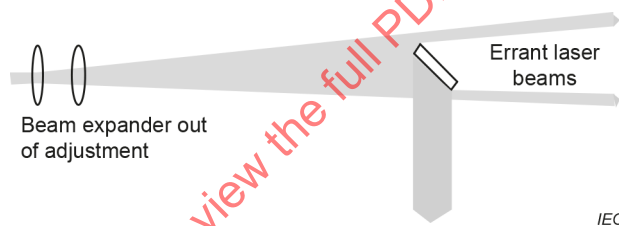


Figure B.4c – Beam expands beyond range of optics

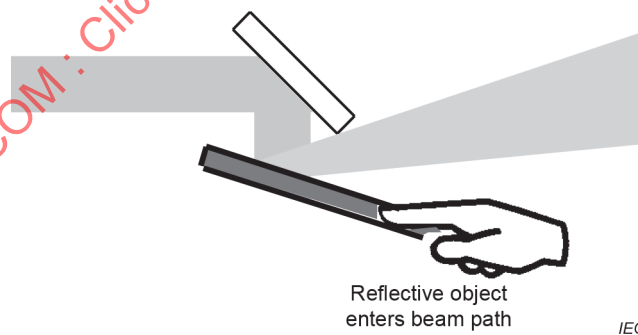


Figure B.4d – Reflective objects intercept laser beam

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

B.4 Exposure duration

B.4.1 Normal operation

The exposure of a guard to laser radiation during fault-free operation may comprise exposures to low levels of reflected, scattered and transmitted radiation which are repeated on each machine cycle. In this case, the assessed FEL for fault-free operation would encompass the variation in irradiance of the guard during the cycle, see Figure B.5, repeated for the maximum number of machine cycles within a safety maintenance inspection interval.

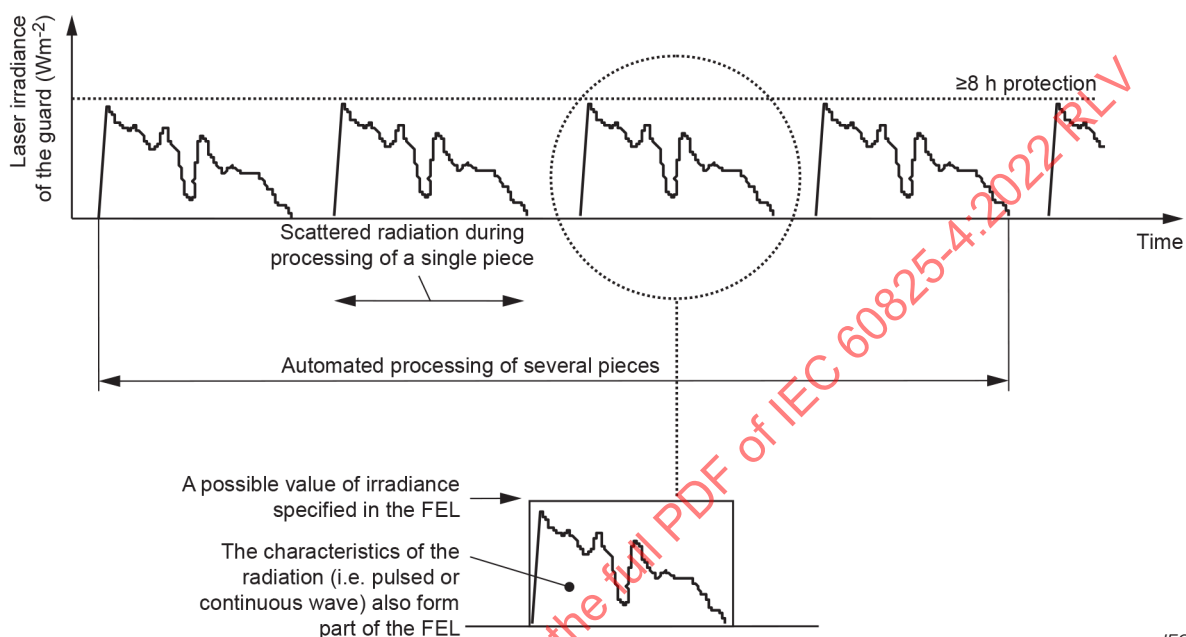


Figure B.5 – Illustration of laser guard exposure during repetitive machine operation

B.4.2 Fault conditions

A safety control system involving some form of machine monitoring can reduce the time for which the guard ~~must~~ **shall** safely contain the radiation hazard under fault conditions. Two examples are given in Figure B.6.

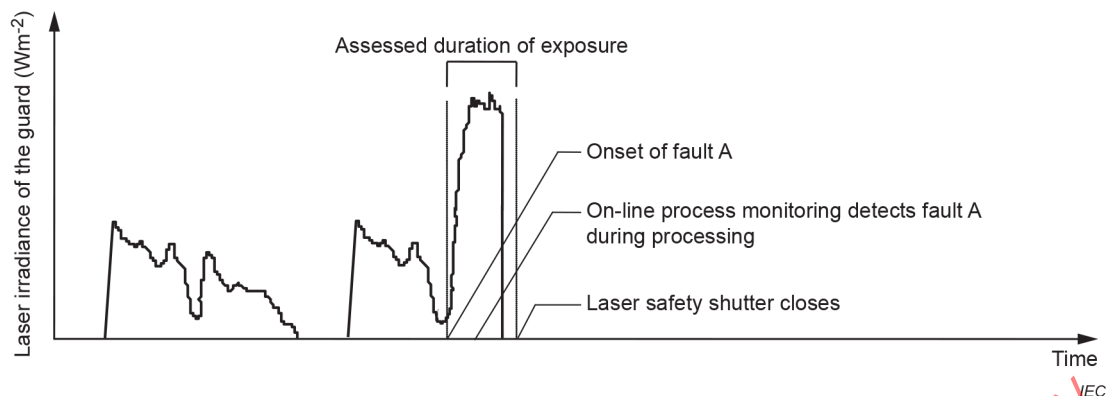


Figure B.6a – Shut-down with on-line machine safety monitoring

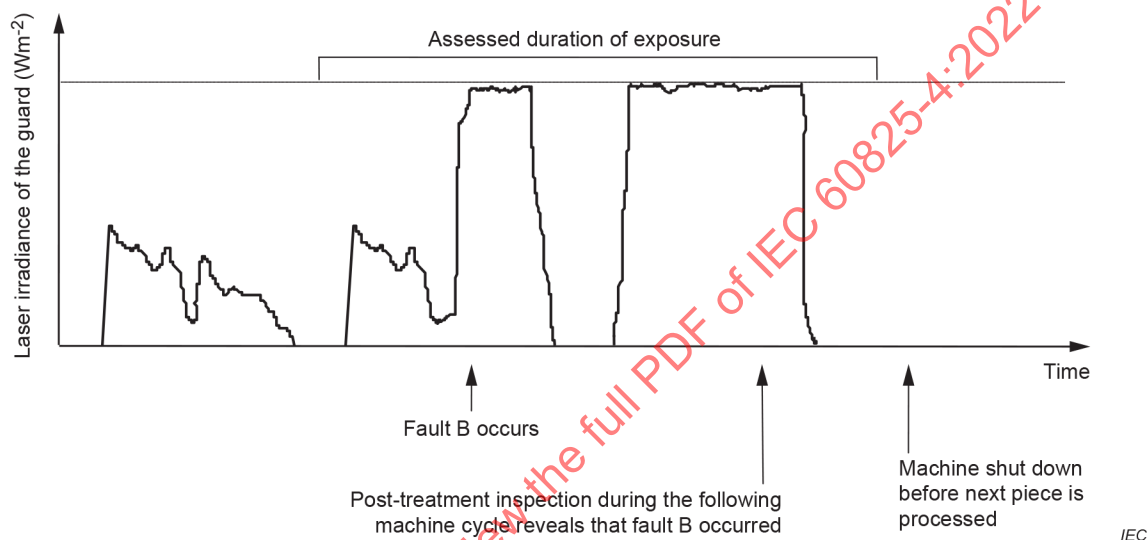


Figure B.6b – Shut-down with off-line machine safety monitoring

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.

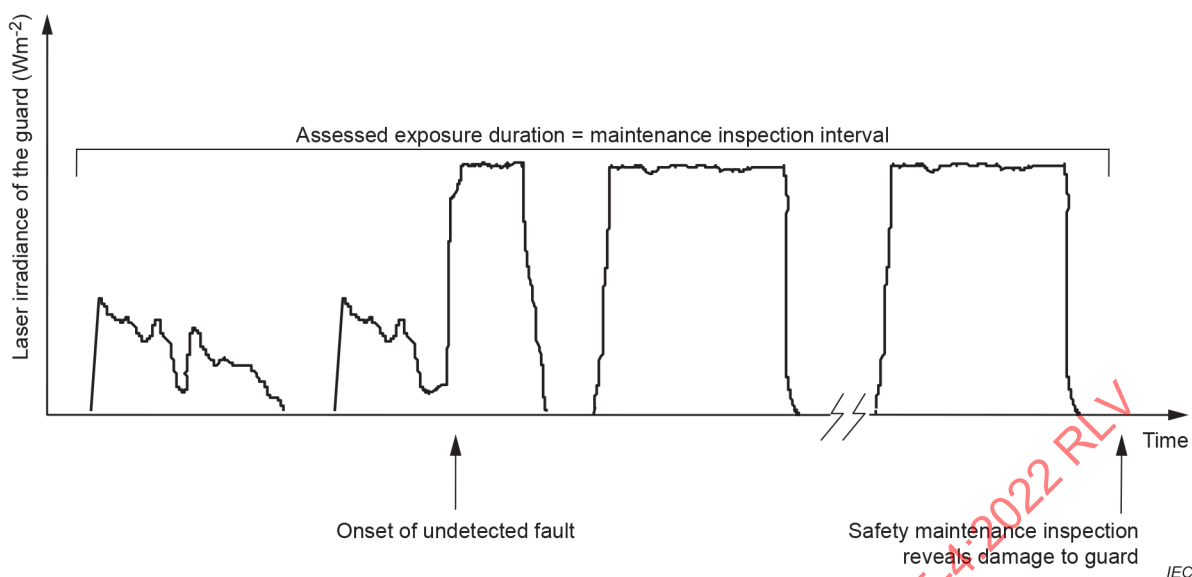


Figure B.7 – Assessed duration of exposure for a machine with no safety monitoring

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.

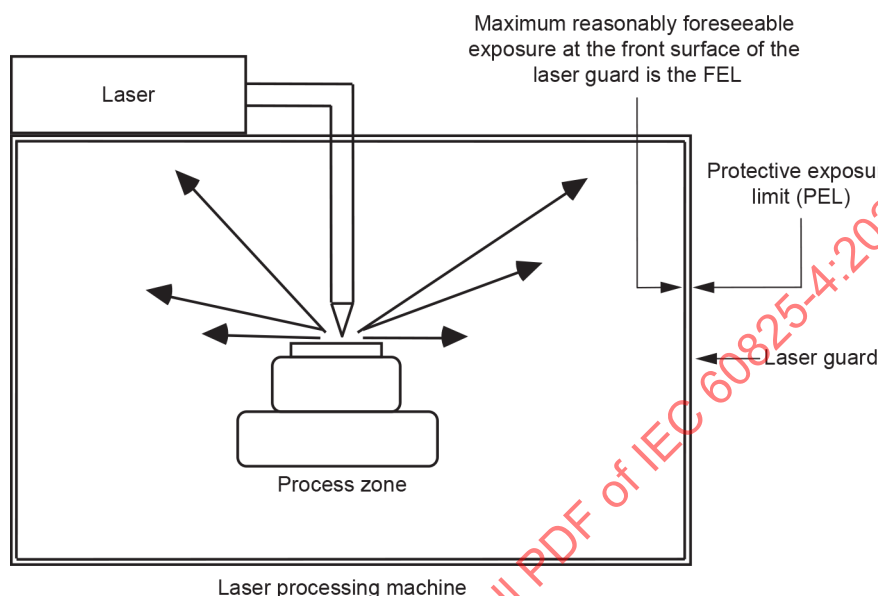
B.5 Reference document

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

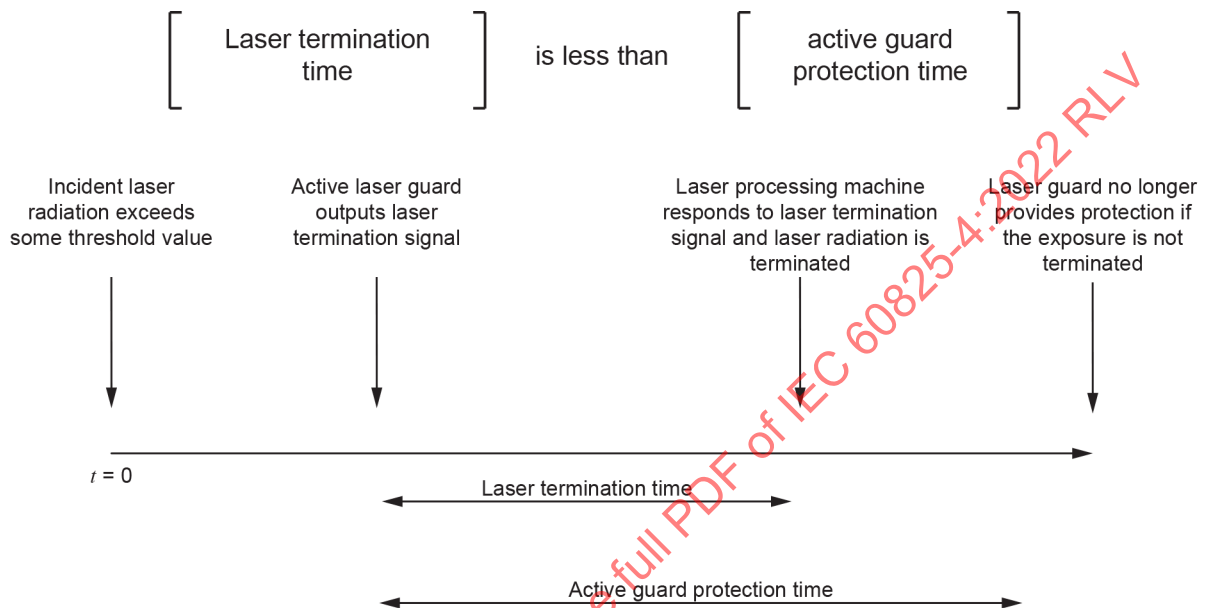
An active guard has two essential components:

- 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 sensor

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



IEC

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 .

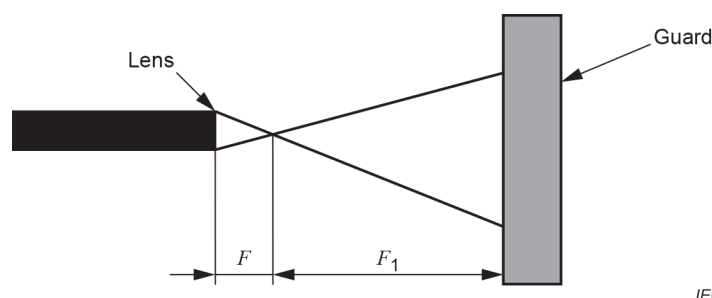


Figure D.1 – Simplified diagram of the test arrangement

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.

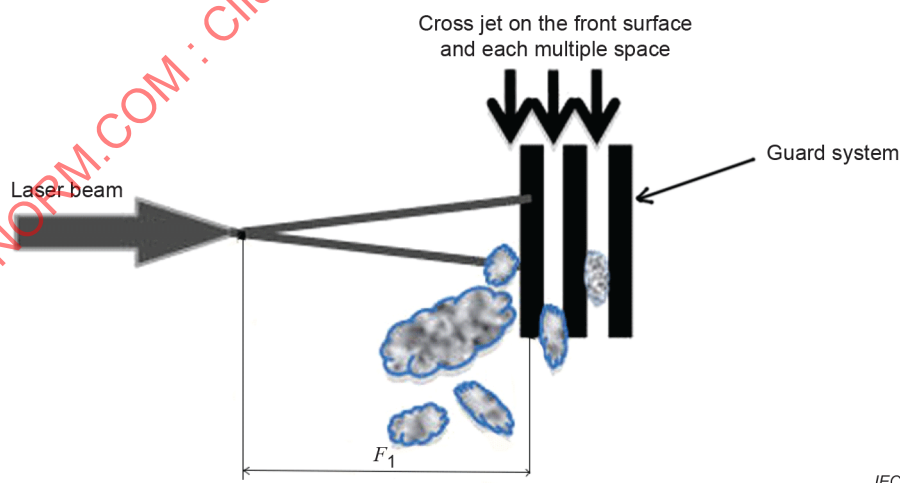


Figure D.2 – Simplified diagram of the ventilation for the guard under test

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 if 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.

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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 ~~14124~~ 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 hardware 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.

F.6.2.3 Glass

Glass is unsuitable for guard manufacture due to its tendency to rupture. However, where a laser process is required to be observed and the material is likely to be exposed to high temperatures or abrasive action, a safety glass, which provides adequate protection from laser radiation (by internal absorption of the laser radiation within the material or suitable reflective optical coatings on the surface of the guard material), may be suitable. Methods for determining the suitability of such materials are given elsewhere in this document.

F.6.2.4 Plastics

Transparent plastic sheet materials may be used in laser guarding as an alternative to opaque materials especially where observation is required during the processing operation.

Plastic materials available for guarding purposes include polycarbonate and specially dyed acrylic sheet. It is essential that these materials are selected with appropriate optical protective properties for the wavelength and power of the laser source fitted to the laser processing machine.

The mechanical properties of many plastics are adversely affected by contaminants, by incorrect cold working and by continuous exposure to high temperatures or UV radiation. Continuous exposure to high temperature (polycarbonate: 135 °C, acrylic sheet: 90 °C) will cause softening and consequently lowering of both impact strength and other optical properties.

Any removal of the surface material may reduce the optical protective properties of the material at laser wavelengths and the provision of additional sacrificial mechanical protective layers should be considered.

Most plastics have an ability to hold an electrostatic charge. This can create a risk of electrostatic ignition of flammable materials and can also attract dust. This characteristic can be mitigated by the use of an anti-static preparation.

F.6.2.5 Other materials

Concrete block work may be an effective material for some guard construction and is frequently used for large CO₂ laser processing machine enclosures.

F.6.3 Supports

Guards may be fastened to independent supports or to the machinery itself. The number and spacing of the fixings should be adequate to ensure stability and rigidity of the guard.

Where necessary, there should be clearances around the guard for cleaning and debris removal, etc., provided that this clearance does not allow access to the hazard zones.

F.6.4 Cover plates

Removable panels or cover plates may be incorporated into guards to provide easy access or improved visibility. They should be treated as part of the guarding system and may be considered as either fixed or interlocking guards depending upon the process requirements.

F.6.5 Anthropometrical considerations

Guards should be designed and constructed with the object of preventing any part of the body from reaching the danger zone. They should take into account the physical characteristics of the people involved and in particular their ability to reach through openings and over or around barriers used as guards. The best approximation of currently available data for human body measurements (anthropometrical data) is given in ~~ISO 15532-3~~ ISO/TR 7250-2.

F.7 Other safety devices

F.7.1 Trip devices

A trip device is a device which causes working machinery to stop, or assume an otherwise safe condition, to prevent injury when a person approaches the danger zone beyond a safe limit. The device will be required to keep the machine in this condition while the person remains within the danger zone unless other means of fulfilling this function are provided.

A trip device should be designed to ensure that an approach to a hazard or danger zone beyond a safe limit causes the device to operate and the hazard to be terminated before injury can be inflicted.

A trip device should be designed so that after it has been operated it may be reset automatically or manually; restarting should then be by means of the normal start actuator. The trip device operation should not be impaired by any extraneous influences.

F.7.2 Electro-sensitive protection equipment

Electro-sensitive protective equipment is sometimes referred to as intangible barriers and operates as trip devices on the principle of detecting the approach of persons or parts of persons into danger zones, etc. The means of detection can be active opto-electronic, active opto-electronic responsive to diffuse reflection, passive infra-red, capacitance, inductive, microwave, or visual intrusion. The effectiveness of the complete installation will depend not only on the integrity of the electro-sensitive protective equipment, but also on the electrical and mechanical integrity of the remaining installation, and the location of the electro-sensitive protective equipment sensing device relative to the danger zone.

F.7.3 Control systems (keys, pressure-sensitive mats, light curtains)

F.7.3.1 Captive-key systems

Generally a captive-key interlocking device is a combination of an electrical switch with a mechanical key operated lock secured to the fixed part of the machine. The operating key is held captive on the moveable part of the guard. To open the guard, the key is turned, which puts the switch into the "off" position and releases the key from the lock so that the guard can be opened.

Some captive-key systems are made up of trapped-key interlocking systems. In a trapped-key interlocking system the guard lock and a switch that incorporates a lock, are separate as opposed to being combined into a single unit. The essential feature of the system is that the removable key is trapped either in the guard lock, or in the switch lock. The lock of the guard is arranged so that the key can be released only when the guard has been closed and locked. This allows transfer of the key from the guard to the switch lock. Closing the switch traps the key so that it cannot be removed when the switch is in the "on" position.

F.7.3.2 Pressure-sensitive mats

Pressure-sensitive mats and floors contain sensors that operate when a person or object applies pressure to the mat or floor. They should be subject to periodic maintenance and inspection, since by their nature, pressure-sensitive mats are exposed to potential damage that can result in failure.

The dimension of mats should take into account a person's speed of approach, length of stride and the overall response time of the protective device. Care should be taken that access cannot be gained without actuation of the mat or floor. Account should be taken of dead surfaces within the mat especially around their edges, when a number of mats are used together. Guidance on the application of pressure-sensitive mats may be found in IEC TS 62046. A pressure-sensitive mat may be appropriate to indicate the presence of a person inside the machinery and/or stop the machinery if required.

F.7.3.3 Light curtains

Light curtains often operate on the principle of the detection of an obstruction in the path taken by a beam or beams of light. The intangible barrier operated by this system may consist of a single light beam device or a number of light beam devices arranged as a curtain. The curtain also may be created by a scanning light beam or a number of fixed beams. The light may be visible or invisible. The requirements for the design and performance of these devices for protective purposes are specified in IEC 61496-2.

F.8 Interlocking considerations

F.8.1 Functions of interlocks

An interlock provides the connection between a guard and the control system of the laser processing machine to which the guard is fitted. The interlock and the guard with which it operates should be designed, installed and adjusted so that:

- a) until the guard is closed the interlock prevents laser emission by interrupting the laser beam either by means of a beam attenuator or by removal of power from the laser;
- b) either the guard remains locked closed until the risk of injury from the hazard has been removed, or opening the guard causes the hazard to be eliminated before access is possible.

Care should be taken to ensure that actuation of an interlock installed to protect against one hazard does not create a different hazard.

F.8.2 Interlocking media

The four media most commonly encountered in interlocking are electrical, mechanical, hydraulic and pneumatic. Electrical interlocking, particularly in control systems, is the most common. The principles of interlocking apply equally to all media. Each has advantages and disadvantages, and the choice of interlocking medium will depend on the type of laser processing machine and the method of access to hazard zones.

Some interlocking systems have more than one control channel, e.g. dual control systems. It is often advantageous to design these systems so that similar failures in both channels from the same cause (common cause failures) are minimized.

F.8.3 Common interlocking methods

F.8.3.1 Guard locking power interlocking

With guard locking power interlocking, the power medium is interrupted directly by a single device which is arranged so that:

- a) the device physically prevents the guard from being opened while the power medium is uninterrupted;
- b) the device is physically held by the guard in the position which is interrupting the power medium when the guard is open.

F.8.3.2 Interlocking guard power interlocking

With interlocking guard power interlocking, the power medium is interrupted directly by a single device that is automatically operated by movement of the guard. The guard and device should have been arranged so that the power medium is interrupted as the guard is opened, and remains interrupted while the guard is in any position other than closed.

F.8.3.3 Dual-control system interlocking with cross monitoring

In dual-control system interlocking with cross-monitoring, there are two separate power interrupting devices, each capable of interrupting the power medium. The devices should be arranged in series, so that the operation of either will result in the interruption of the power medium. These are operated by individual devices actuated by the guard.

The power interrupting devices should have been monitored so that the failure of either their control systems or the interrupting devices themselves, to respond to the control system signal will be immediately detected and a further operating cycle of the laser processing machine prevented. The circuitry of each power interrupting device, including its operating device, should be kept physically separated as far as is practicable, to reduce the probability of the interlocking system failing to danger as a result of common cause failures.

F.8.3.4 Dual-control system interlocking without cross monitoring

Dual-control system interlocking without cross-monitoring follows the same principles as those described above but without the facility to monitor automatically the correct functioning of the two power interrupting devices.

In the absence of automatic monitoring, it is possible for either interlocking channel to fail to danger and for the fault to remain undetected, which then reduces the integrity of the system to that of single-control system interlocking. For dual-control system interlocking without cross-monitoring to function effectively, however, it is important that a regular check is carried out to ensure that both channels are working correctly. The frequency of checking will depend on the reliability of the components used and the conditions under which the interlocking system is operating.

F.8.3.5 Single channel system interlocking

Single-control system interlocking employs an interlocking device which indirectly interrupts the power medium by operating a single power interrupting device via a control system. It does not have a high level of integrity because of the greater possibility of single component failure in the system causing the whole system to fail to danger. The system, therefore, should have been designed and installed using the minimum number of components.

The system should be inspected and tested regularly and any worn or damaged components replaced or repaired.

F.8.4 Failures of interlocking systems

F.8.4.1 General

Interlocking systems should be designed to minimize the possibility of the interlocking system as a whole to fail to danger.

As power supplies frequently fail, components relying on the power supply for their functioning should be installed so that power loss minimizes failure to danger of the system as a whole.

F.8.4.2 Types of failure

The most common types of failure from which an interlocking system may suffer are:

- a) failure, interruption or variation of externally supplied power;
- b) open circuits in electrical systems;
- c) mechanical failure, e.g. breakage or seizure;
- d) malfunction due to electrical environment, i.e. mains borne or radiated disturbance;
- e) malfunction due to vibration;

- f) malfunction due to power supply contamination;
- g) earth faults, i.e. accidental connection of a conductor to earth causing, for example, unexpected start-up or failure to stop;
- h) other single component failures leading to change of characteristic or loss of function;
- i) cross-connection failures causing, for example, unexpected start-up or failure to stop.

Measures can be taken to minimize the consequences of single failures in interlocking systems. These may include the use of additional control or monitoring circuits. However, the system as a whole can still fail due to multiple undetected failures, e.g. common cause failures or undetected failures followed by further failure.

Common cause failures may typically result from:

- a) external environment e.g. contamination from dust, electrical disturbances, extreme temperatures, vibration or radiation;
- b) components from a substandard batch being used in each channel;
- c) damage due to localized fire or impact.

F.8.5 Security of interlocking systems

The security of an interlocking system can be improved by avoiding motives for its defeat and/or by making defeat more difficult.

The design of the safeguarding system should have taken full account of the need for human intervention in the machine during any phase of its life.

Ways in which defeat may be made more difficult include:

- a) the use of interlocking devices or systems which are coded;
- b) physical obstruction or shielding of the interlocking device while the guard is open.

F.8.6 Integrity of interlocking systems

The integrity of an interlocking system will depend not only on the direct effects of failures or defeats, but also whether or not those failures or defeats lead to damage to other components or interconnections within the system. Therefore, an important consideration should be circuit protection.

Other basic criteria for improving the integrity of an interlocking system include:

- a) correct installation;
- b) good quality, high integrity components, protected to withstand the environment (including possible reflections of laser energy) and rated for the duty they have to perform;
- c) minimizing by design, manufacture and correct installation, the probability of an earth fault occurring;
- d) minimizing failure to danger;
- e) minimizing defeat.

F.8.7 Choice of interlocking system

Interlocking systems should be selected for particular applications taking account of:

- a) the frequency with which approach to the danger zone is required;
- b) the probability and severity of injury should the interlocking system fail;
- c) the resources required to reduce the risk of injury.

F.8.8 Electrical considerations

Electrical control systems can fail in ways that could result in hazardous situations. Particular attention should be paid to minimizing the probability of this occurring. IEC 60204-1 gives guidance.

Devices should be selected only from those where the performance, as stated by the manufacturer, is suitable for the specific safety application. The following performance data should be considered:

- a) resistance to environmental conditions;
- b) life evaluation;
- c) duty rating;
- d) reliability.

Proximity switches which rely solely on the presence or absence of metal for their actuation are not generally suitable for interlocking duties because they can be easily defeated. However with careful design, these devices can be incorporated into difficult to reach or small assemblies. Extreme care ~~must~~ needs to be taken to prevent the devices being defeated and suitable redundancy used to prevent common cause failures resulting in an overall failure to danger.

F.8.9 Mechanical considerations

F.8.9.1 Interlocking devices

Mechanical devices for connecting guard movement with the machine power or control system can take various forms but will generally perform the same function. They will usually be arranged so that operation of the guard and the machine can only be carried out in a correct safe sequence.

F.8.9.2 Mechanical interlocking methods

Unlike electrical, hydraulic or pneumatic systems, it is unusual for mechanical systems to be other than a single-control system.

The basic elements of single-control system interlocking are:

- a) the actuating device operated by the guard;
- b) interposed mechanical linkages, if any;
- c) the device for preventing the emission of laser radiation or preventing the power to any other hazard.

Reducing the number of interposed linkages reduces the probability of the system failing to danger.

F.8.10 Pneumatic and hydraulic considerations

F.8.10.1 Interlocking devices

Devices used for interfacing guard movement include:

- a) cam-operated valves;
- b) captive-key valves; tap-key control of pneumatic valves;
- c) pneumatic jet detection valves;
- d) pneumatically or hydraulically operated locks.

When valves are selected for safeguarding applications, the valve operating parameters (pressure, temperature, etc.) and reliability should be suitable for the environment and the duty envisaged.

F.8.10.2 Pneumatic or hydraulic interlocking methods

In general, interlocking methods as described in F.8.3 are applicable. These methods include:

- a) single-control system interlocking;
- b) dual-control system interlocking with or without cross-monitoring;
- c) power interlocking.

All piping, hoses, etc., between control valves and interlocks should be suitable for the fluid and operating environment, correctly sized and rated for maximum flow and pressure and, where necessary, further effectively protected and securely mounted. Pipework fittings should be selected to ensure their integrity does not compromise the overall integrity of the interlocking system.

F.9 Environmental considerations

F.9.1 Environment

The selection of a safeguard should take into consideration the environment in which it is used. In a hostile environment it should be capable of withstanding the conditions likely to be experienced and should not of itself create a hazard as a result of that environment.

F.9.2 Corrosion

If a guard is likely to be exposed to a corrosion risk, special measures should be taken. The use of corrosion-resistant materials or corrosion-resistant surface coatings should be considered.

F.9.3 Hygiene and guard design

Guards used in certain industries, notably for processing of food or pharmaceuticals, should be so designed that they are not only safe to use but can be readily cleaned. Materials used for safeguards should be non-toxic, non-absorbent, shatterproof and readily cleanable and be unaffected by the material being processed or by cleaning or sterilizing agents.

F.9.4 Mist, fumes and dust

Where the process gives rise to hazardous or objectionable levels of vapours, fumes or dust, containment or suitable extraction equipment should be provided. The levels of exposure to vapours, fume or dust should conform to the occupational exposure limits and occupational exposure standards for local control of substances hazardous to health.

F.9.5 Noise

Consideration should be given to noise reduction when designing safety enclosures and guards. It is often possible for guard enclosures to be designed to serve a dual purpose of protecting against laser radiation hazards together with mechanical hazards and reducing noise emissions. Guards should not add to the noise levels because of poor design or fixing.

F.10 Installation consideration – Environmental factors – Services

F.10.1 Lighting

When considering the lighting in relation to the laser processing machine the following aspects affect the safety of the people involved:

- a) the direction and intensity of the light;
- b) the contrast between the background and local illumination;
- c) the colour of the light source;
- d) reflection, glare and shadows;
- e) the visual wavelength transmission characteristics of viewing windows.

F.10.2 Cables and pipes

Service pipes and cables should either be placed outside of the process zone or, when this is not possible, provided with covers of adequate strength and capable of tolerating laser radiation exposure under foreseeable fault conditions.

F.11 Maintenance and service considerations

F.11.1 Operational maintenance of safeguards

The maintenance of safeguards, once they are taken into use, is essential to their continued effectiveness.

There should be regular inspection of safeguards to ensure that the requisite standard of safety is maintained. The routine inspection of safeguards should be made as part of a planned maintenance programme.

F.11.2 Properties of laser guard materials

By way of illustration, Figure F.1 to Figure F.22 provide some experimentally-determined limits of laser beam power and beam diameter for burn-through times of 10 s or 100 s for various metal sheets: the sheets were mounted vertically and the front surface painted black; and the laser beam was horizontal. Burn-through time is the time taken for the laser beam to remove the material in its path (e.g. by melting, vaporization, ablation) and the data should be taken only as a guide, since values can vary widely depending on the beam parameters (including wavelength and beam profile) and the condition of the guard surface.

The performance of a laser guard may also be dependent on its particular design and application; and it is recommended that the suitability of a laser guard design is verified by adequate performance testing.

Some examples of various guard materials are shown in Figure F.1 to Figure F.22.

Figure F.1 – 1 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.2 – 1 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.3 – 2 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.4 – 2 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.5 – 3 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.6 – 3 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.7 – 2 mm thick aluminium sheet for CW CO₂ laser

Figure F.8 – 2 mm thick aluminium sheet for CW CO₂ laser

Figure F.9 – 1 mm thick stainless steel sheet for CW CO₂ laser

Figure F.10 – 1 mm thick stainless steel sheet for CW CO₂ laser

Figure F.11 – 6 mm thick polycarbonate-~~steel~~ sheet for CW CO₂ laser

Figure F.12 – 6 mm thick polycarbonate-~~steel~~ sheet for CW CO₂ laser

Figure F.13 – 1 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.14 – 1 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.15 – 2 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.16 – 2 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.17 – 3 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.18 – 3 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.19 – 2 mm thick aluminium steel sheet for CW Nd:YAG laser

Figure F.20 – 2 mm thick aluminium steel sheet for CW Nd:YAG laser

Figure F.21 – 1 mm thick stainless steel sheet for CW Nd:YAG laser

Figure F.22 – 1 mm thick stainless steel sheet for CW Nd:YAG laser

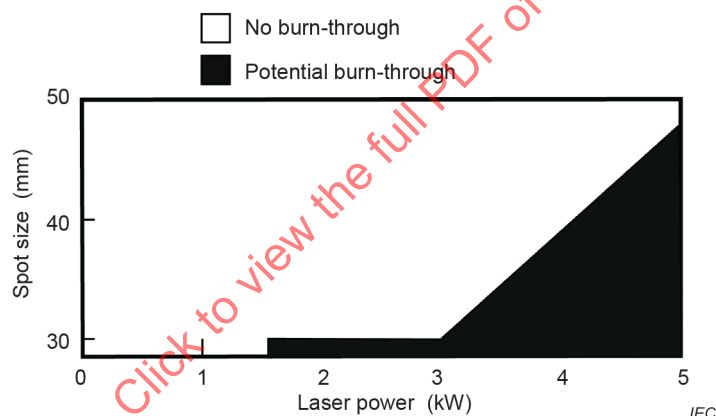


Figure F.1 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

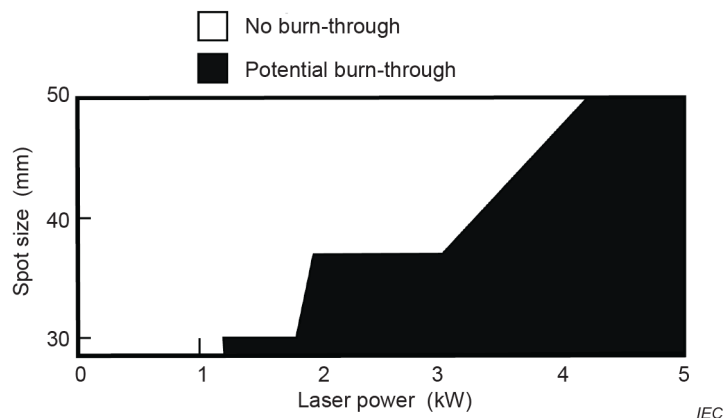


Figure F.2 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

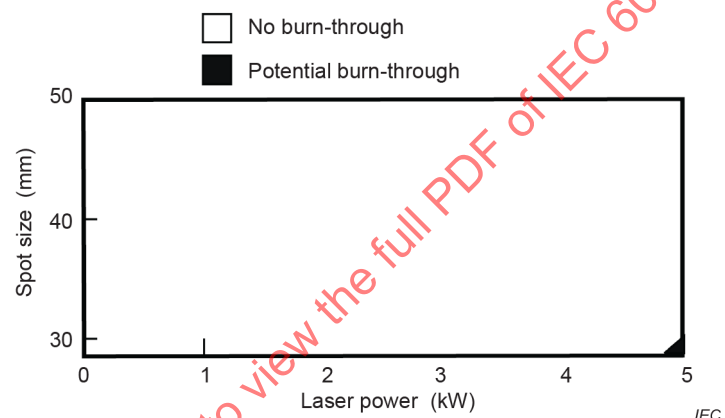


Figure F.3 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

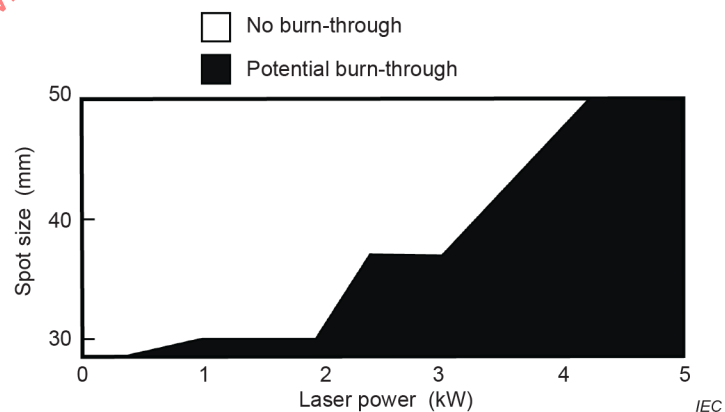


Figure F.4 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

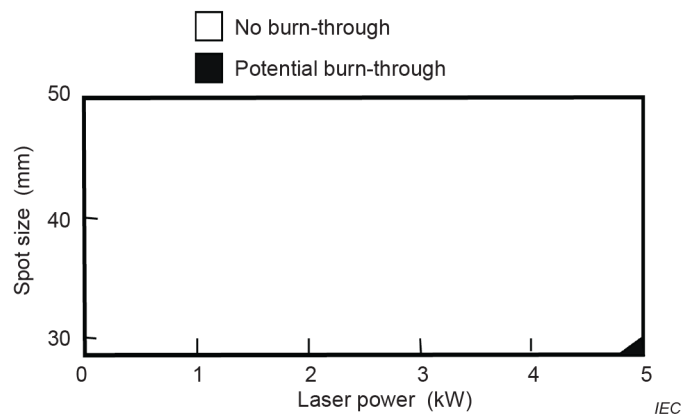


Figure F.5 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

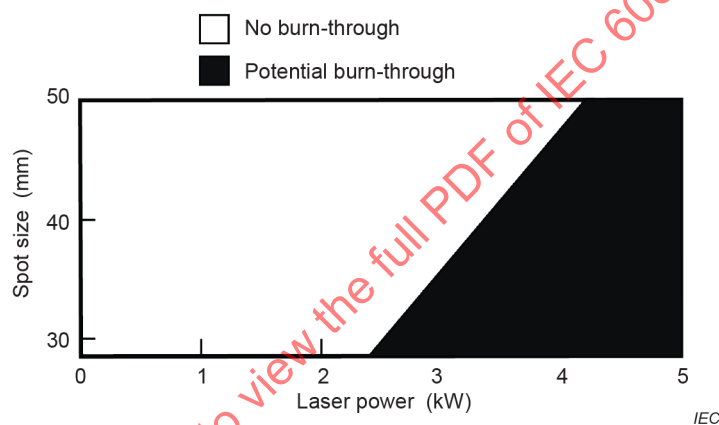


Figure F.6 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

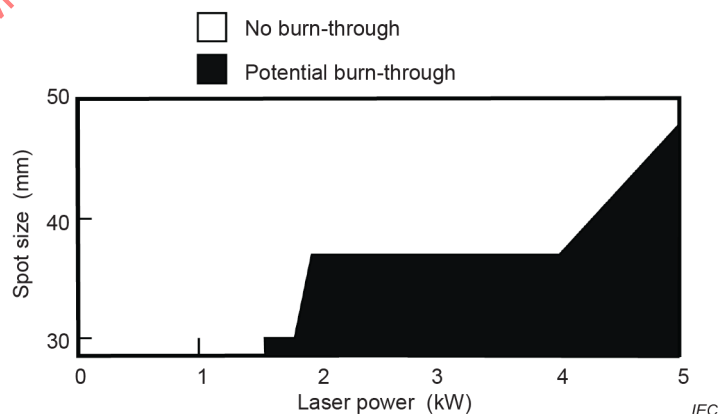


Figure F.7 – Damage resistance of 2 mm thick aluminium sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

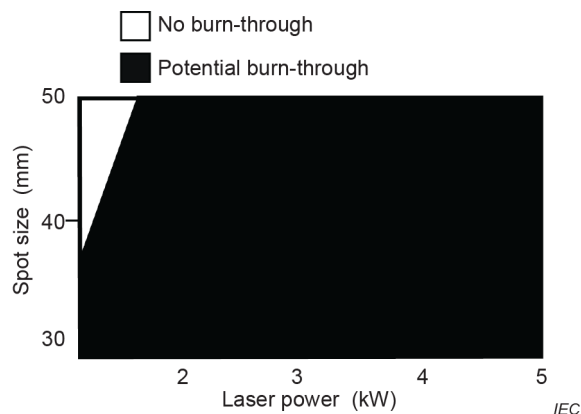


Figure F.8 – Damage resistance of 2 mm thick aluminium sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

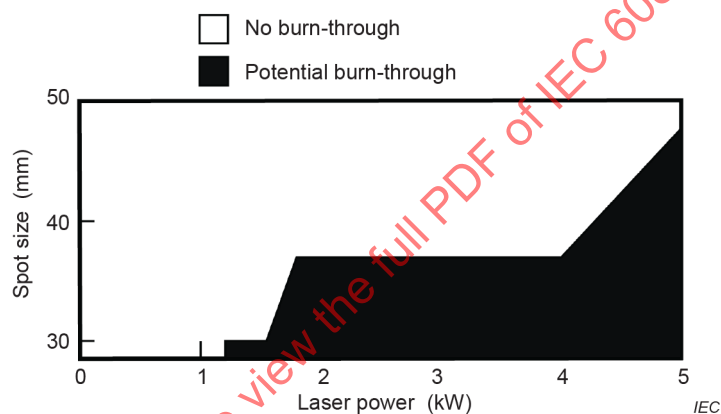


Figure F.9 – Damage resistance of 1 mm thick stainless steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

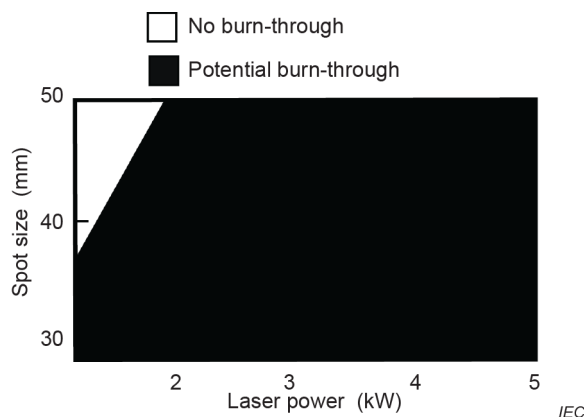


Figure F.10 – Damage resistance of 1 mm thick stainless steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

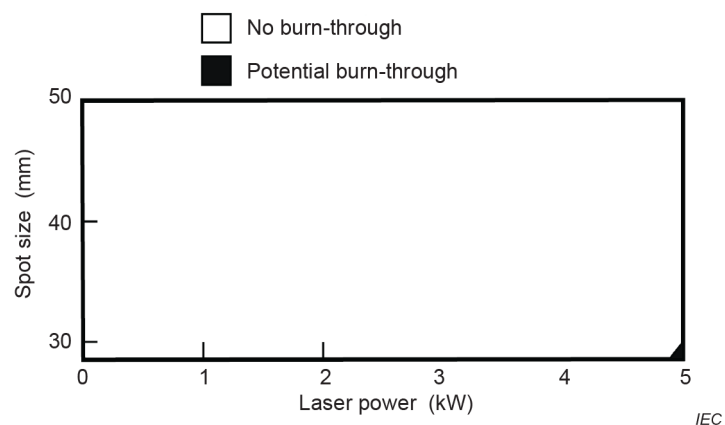


Figure F.11 – Damage resistance of 6 mm thick polycarbonate sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

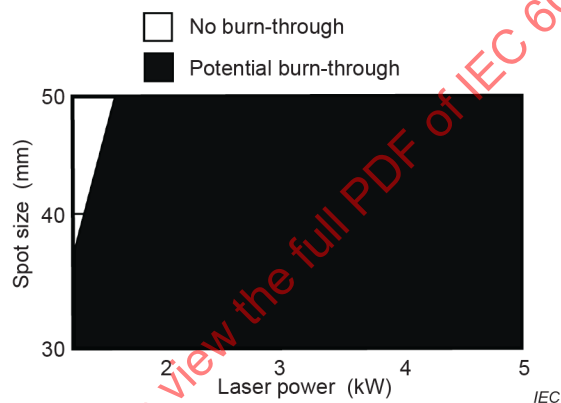


Figure F.12 – Damage resistance of 6 mm thick polycarbonate sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

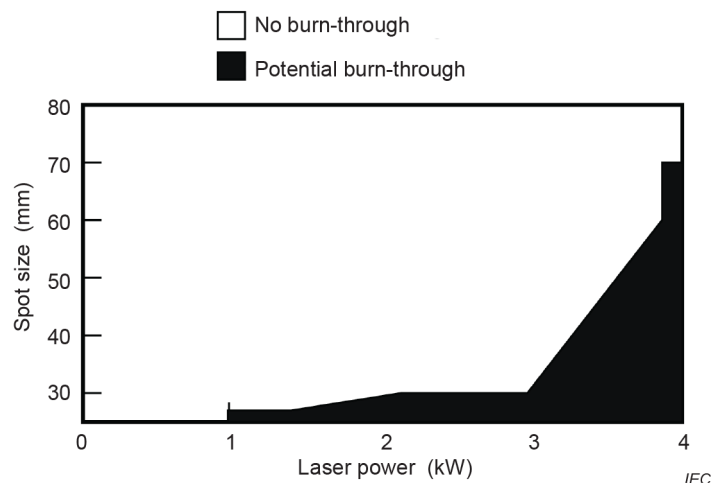


Figure F.13 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

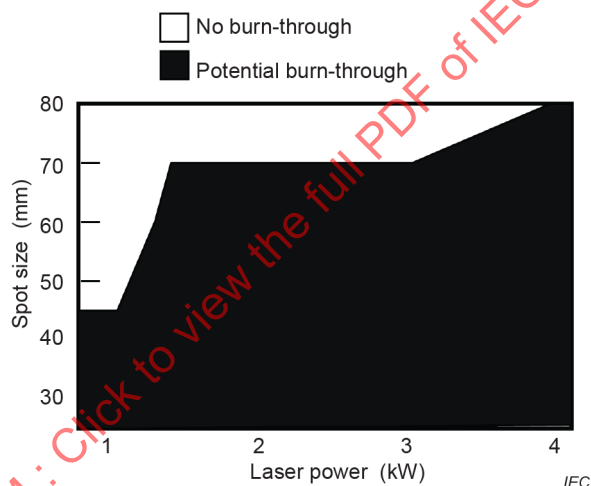


Figure F.14 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

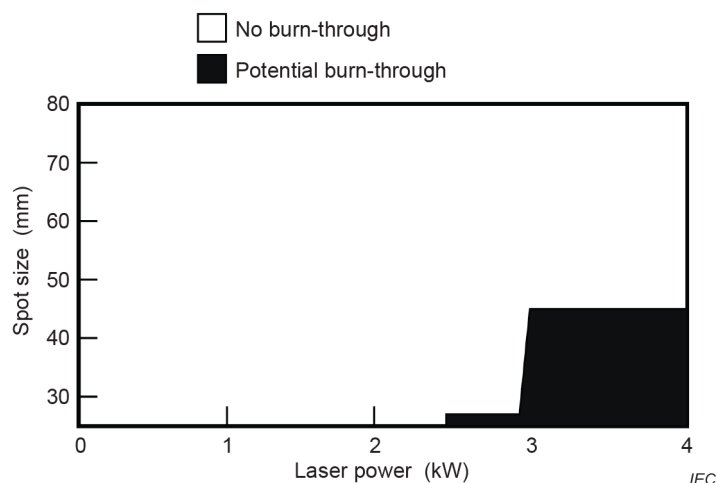


Figure F.15 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

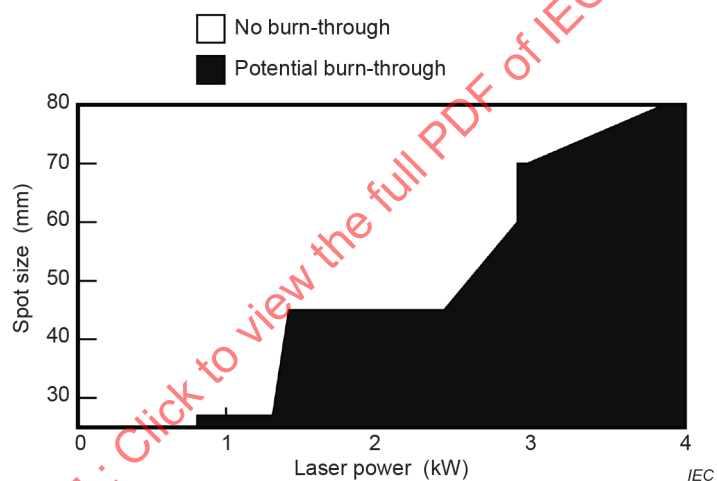


Figure F.16 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

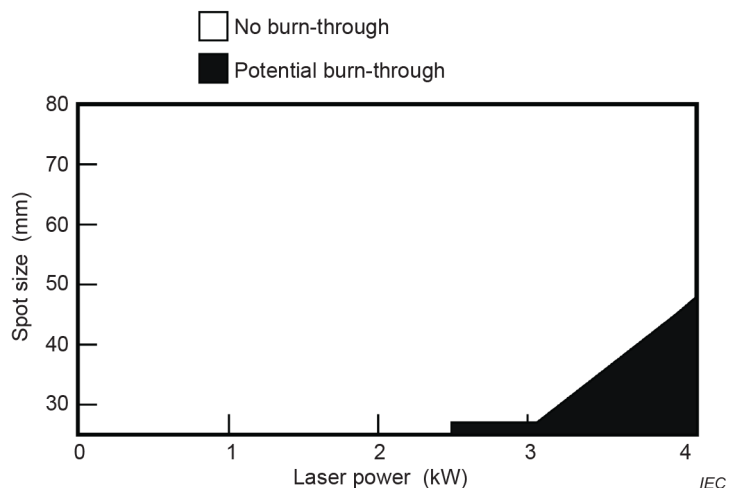


Figure F.17 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

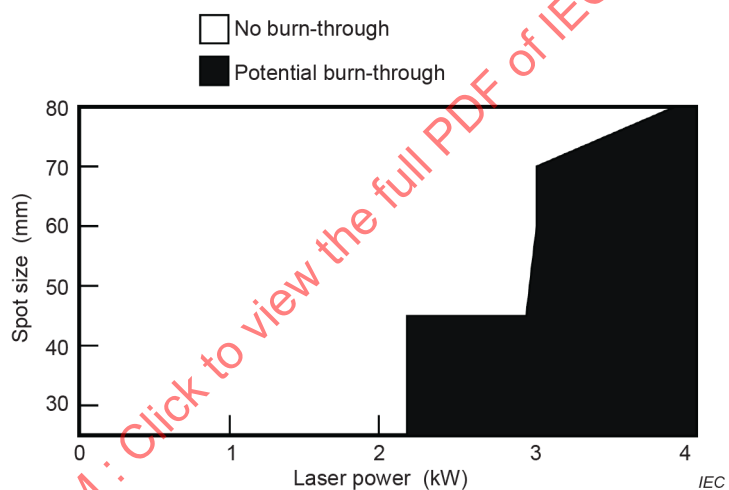


Figure F.18 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

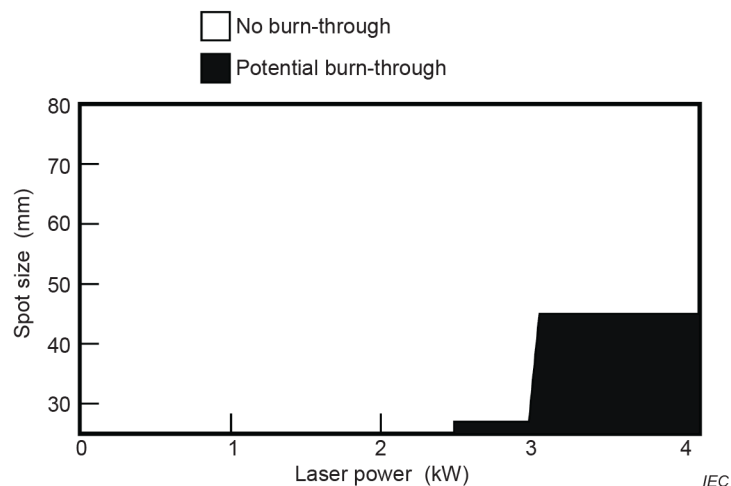


Figure F.19 – Damage resistance of 2 mm thick aluminium sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

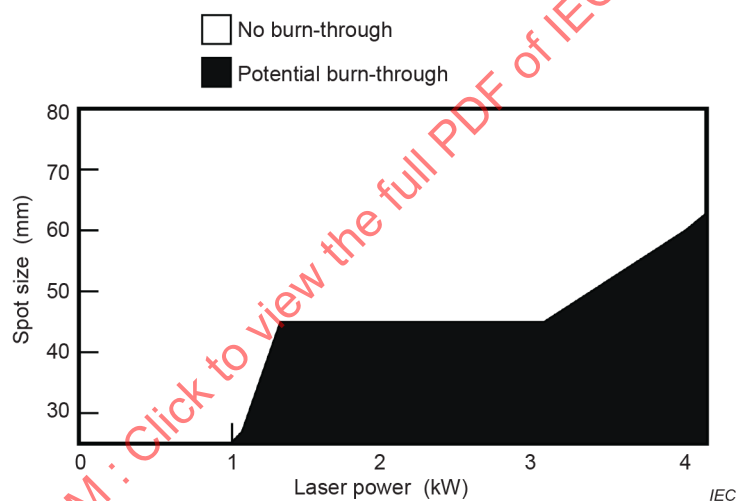


Figure F.20 – Damage resistance of 2 mm thick aluminium sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

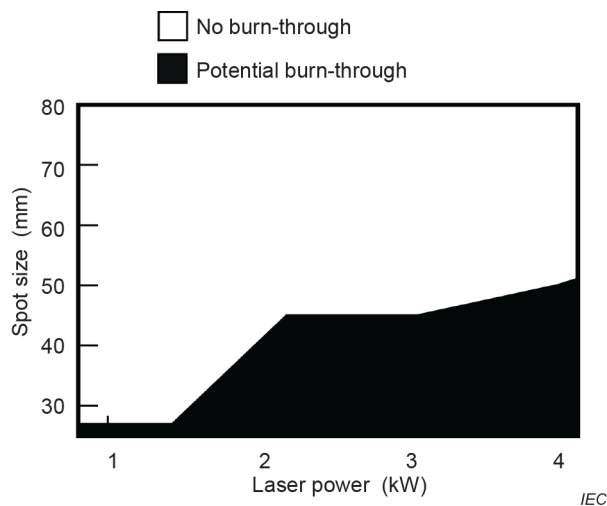


Figure F.21 – Damage resistance of 1 mm thick stainless steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

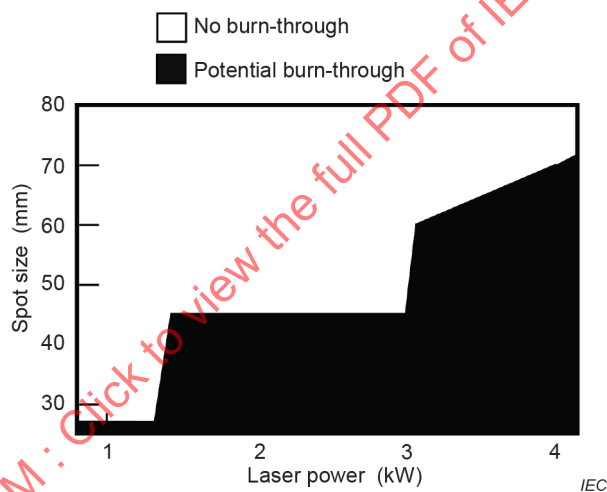


Figure F.22 – Damage resistance of 1 mm thick stainless steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

Annex G (normative)

Guided beam delivery systems

G.1 General

Annex G addresses the arrangement, installation and use of guided beam delivery systems. Laser beams can be propagated through air, gas or vacuum, whether enclosed or not (free space), and through fibre optic cables in laser processing machine applications.

Annex G applies to the protective measures implemented to protect personnel against laser radiation hazards for guided beam delivery systems after the output coupler and/or the protective housing of the laser product (the requirements of which are specified in IEC 60825-1). Annex G is intended to complement the requirements applicable to the laser process enclosure (which are specified in this document and in ISO 11553-1). Annex G also provides methods for assessing the risks (including reasonably foreseeable use, abuse and misuse) and provides examples of control measures to meet the normative requirements of IEC 60825-1 and this document.

~~This annex does not apply to beam delivery systems inside the protective housing of the laser.~~

~~This annex does not apply to beam delivery systems used in medical or communications applications.~~

Annex G is not applicable to

- a) embedded beam delivery components and systems inside the protective housing of the laser radiation generator;
- b) communications applications;
- c) medical applications.

~~G.2 Terms and definitions~~

~~For the purposes of this annex, the following definitions apply. They are in addition to those given in IEC 60825-1 or other parts of IEC 60825.~~

~~G.2.1~~

~~access panel~~

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

~~G.2.2~~

~~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. 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~~

~~G.2.3~~

~~beam path components~~

~~those optical components which lie on a defined beam path (see 3.16 of IEC 60825-1)~~

NOTE Examples of a beam path component include a beam steering mirror, a focus lens or a fibre optic cable connector.

G.2.4

beam shaping components

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

G.2.5

beam switching components

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

G.2.6

fibre optic cable

optical beam guiding component that enables the transmission of laser radiation along a transparent medium. 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. For this annex, this term also includes other forms of transmission devices such as waveguides

G.2 General requirements

G.2.1 General considerations

The risks associated with the hazards relevant to the beam delivery systems shall be assessed as part of the overall requirements for risk assessment of the machine. The principles for risk assessment given in ISO 14121-1:2010 shall be used in carrying out this assessment. This assessment shall determine the acceptable level of risk and the necessary protective measures for persons who can be exposed to those hazards, while maintaining an acceptable level of performance of the machine.

Hazards can result from, but are not limited to, the following causes:

- a) failures, faults or damage in the protective housing or other mechanical protective measures incorporated in the beam delivery system resulting in the inadvertent emission of laser radiation from the protective housing;
- b) failures or faults in the beam path components resulting in damage to the protective housing or other protective devices;
- c) failures or faults in the associated equipment or controls resulting in injury or malfunction or failure of the safety functions of the laser processing machine;
- d) failures or faults from reasonably foreseeable misuse or abuse resulting in the inadvertent emission of laser radiation from the protective housings.

The engineering and administrative controls adopted are a combination of the measures incorporated at the design stage and include those instructions to be followed by the user.

Design shall be the first consideration in the reduction of risks. Where this is not sufficient to eliminate risks to a negligible level, additional safeguarding and safe working procedures shall be considered.

NOTE Examples of risk assessments and potential solutions for risk reduction measures are shown in Clause G.5.

G.2.2 Protective housing

The requirements for protective housing are specified in 6.2.1 and 6.2.2 of IEC 60825-1:2014.

G.2.3 Access panels and safety interlocks for beam delivery systems using free space transmission

The requirements for access panels and safety interlocks are specified in IEC 60825-1:2014, 6.3.

A safety interlock shall be provided for access panels of protective housings of free space beam delivery systems that may include beam shaping and beam switching components when:

- a) the access panel is intended to be removed or displaced during maintenance or operation of the laser processing machine, and
- b) the removal of the panel gives access to laser radiation levels designated by "X" in Table 13 of IEC 60825-1:2014.

The safety interlock shall be part of a design that prevents the removal of the panel until the accessible emission levels are below the AEL defined above. Inadvertent resetting of the interlock shall not in itself restore emission values above the limits specified in 5.3.

If a deliberate override mechanism is provided, the requirements in 6.3.2 of IEC 60825-1:2014 shall apply.

All safety interlocks, safety monitoring devices or associated safety-related control circuits shall meet the requirements specified in ISO 12100-2 and IEC 61508 (all parts) or ISO 13849-1 with respect to the general requirements for guards together with the requirements related to interlock devices and safety monitoring devices and their application in safety-related control circuits.

G.2.4 Safety interlocks for beam delivery systems using fibre optic cables or other beam waveguides

Removal or displacement of a fibre optic cable (or other form of beam waveguide) in a beam delivery system shall be allowable only under at least one of the following conditions.

- a) With the use of a key or tool at the point of connection to allow access, removal or displacement of the fibre optic cable by skilled or trained persons.
- b) With the prevention of emission from the fibre optic cable by the termination of emission from the laser prior to access to the fibre optical cable end on the removal or displacement of the fibre optic cable. This may be accomplished by the use of interlocks at the interfaces that can be displaced.
- c) Removal or displacement of the fibre optic cable without the use of a key or special tool and without the termination of laser radiation emission from the laser shall be possible only when other protective measures are provided to ensure that personnel are not exposed to laser radiation that will cause injury. These protective measures shall be clearly described in the user instructions together with the necessary procedures for their use.

When a safety interlock is used, removal of the protective housing shall not permit human access to accessible emission levels above the applicable AEL in Table 13 of IEC 60825-1:2014. Inadvertent resetting of the interlock shall not in itself restore emission values above the applicable AEL in Table 13 of IEC 60825-1:2014. These interlocks shall be failsafe or redundant and conform to the requirements in the applicable IEC product standard.

If a deliberate override mechanism is provided, the requirements of 6.3.2 of IEC 60825-1:2014 shall apply.

All safety interlocks, safety monitoring devices or associated safety-related control circuits shall meet the requirements specified in ISO 12100-2 and IEC 61508 or ISO 13849-1 with respect to the general requirements for guards together with the requirements related to interlock devices and safety monitoring devices and their application in safety-related control circuits.

G.2.5 Environmental conditions

All beam delivery systems shall meet the safety requirements defined in Annex G under all expected operating conditions and foreseeable abuse and misuse appropriate to the intended purpose of the laser processing machine. Factors to be considered shall include:

- a) the intended environment of use;
- b) climatic conditions (temperature, relative humidity, etc.);
- c) anticipated vibration and shock;
- d) electromagnetic interferences.

G.3 Verification of safety requirements or protective measures

General conformance with the requirements of Annex G shall be **verified** by visual inspection.

Correct functioning of control devices shall be verified in accordance with functional tests specified by the manufacturer.

Verification procedures relating to laser radiation levels shall conform to IEC 60825-1.

Verification of the information for the user shall be confirmed by visual examination of the handbooks and any other relevant information.

G.4 Information for users

G.4.1 Technical documentation

In addition to the requirements of other standards that are used in the manufacture of the laser processing machine, the following information shall be supplied.

- a) Relevant safety-related documentation and details of safe installation and use of the beam delivery system. This shall, where appropriate, include:
 - 1) a clear, comprehensive description of the beam delivery system, its installation and mounting and any connection to the host equipment safety-related controls;
 - 2) electrical supply and other control requirements;
 - 3) laser radiation performance limitations;
 - 4) information on the relevant physical environment.
- b) Relevant safety-related documentation for maintenance and servicing procedures associated with the beam delivery system. This information shall include guidance on the adjustment, maintenance, replacement and repair, particularly of the protective devices and control for use by authorized service personnel.
- c) List of recommended spare parts for use by authorized service personnel.
- d) A description (including interconnection diagrams) of the safeguards, interlocking functions and interlocking of guards. This description shall include situations when removal or displacement of the fibre optic cable without the use of a key or special tool and without the termination of laser radiation emission from the laser shall be possible and when other protective measures are provided to ensure that personnel are not exposed to laser radiation that will cause injury. These protective measures shall be clearly described together with the necessary procedures for their use.
- e) A description of the means provided, where it is necessary, to suspend the safeguarding.

G.4.2 Labelling

Access panel warning labels shall be fitted as required and described in Clause 7 of IEC 60825-1:2014.

G.5 Examples of risk assessments

Examples of risk assessments are shown below together in Table G.1 and Table G.2 with potential solutions for risk reduction measures. The list is not comprehensive and alternative technical measures (that may have identical or improved efficiency) for risk reduction can be considered.

Table G.1 – Beam delivery systems using free space beam delivery systems

Use, reasonably foreseeable misuse or abuse	Failure mechanism	Hazard	Example of risk reduction
Beam directed through beam switching device.	Beam switch emits the laser beam partly or wholly guided to an unexpected beam delivery system.	Laser radiation above accessible emission limit (AEL) of Class 1 at unexpected beam delivery system.	Design the beam switching device to avoid this.
Beam directed through beam switching device.	Beam switch not in proper position – laser beam partly or wholly guided to unexpected beam delivery system.	Laser radiation above AEL of Class 1 at unexpected beam delivery system.	Monitor the beam switching device and interlock to ensure the beam switch components are in the correct positions.
Beam being propagated through the free space beam path protective housing.	Mirror or lens damage, breakage or contamination leading to higher degree of scattered radiation that may cause deformation of components in the beam delivering system.	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The beam delivery protective housing to be able to tolerate the foreseeable exposure limit (FEL) (as defined in 3.11) as a passive laser guard, or ~~use~~ consider using a correctly designed active guard ~~considered~~. Consider apertures to reduce the amount of radiation scattered from a defective mirror, or limit radiation scattered as a result of misalignment. Monitor the local temperature of vulnerable beam delivery components.
Beam being propagated through the free space beam path protective housing.	Mirror breakage leading to excess heating by the laser beam resulting in the deformation of components in the beam delivering system.	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The beam delivery protective housing to be able to tolerate the FEL as passive laser guard, or ~~use~~ consider using a correctly designed active guard ~~considered~~. Consider apertures to reduce the amount of radiation scattered from a defective mirror, or limit radiation scattered as a result of misalignment. Monitor the local temperature of vulnerable beam delivery components.
Beam being propagated through the free space beam path protective housing.	Mechanical deformations of protective housing. (Damage or deformation due to external forces great enough to temporarily or permanently distort the physical configuration.)	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The beam path protective housing designed to tolerate reasonably foreseeable mechanical forces, or provide an alternative active guard.

Use, reasonably foreseeable misuse or abuse	Failure mechanism	Hazard	Example of risk reduction
Beam being propagated through the free space beam path protective housing.	Displacement of the protective housing due to vibrations etc. that may cause the beam delivery system break-up.	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The use of well-tried proven design methods that tolerate foreseeable operating stresses and widely used with successful results in similar applications. Conduct regular inspection.
Beam being propagated through the free space beam path protective housing.	Misalignment of mirrors.	The beam exposing the protective housing to levels higher than its protective exposure limit (PEL) (as defined in 3.21).	The use of well-tried proven design methods that tolerate foreseeable operating stresses and are widely used with successful results in similar applications. Prevent misaligned beam from propagating further in the beam delivery system. Incorporate apertures and baffles/barriers to restrict propagation. Restrict the number and extent of adjustments.
Beam being propagated through the free space beam path protective housing.	Unclear identification of beam delivery components resulting in incorrect parts being installed and subsequent damage of both the parts themselves and other parts of the machine or workpiece.	Laser radiation above AEL of Class 1 from openings in beam delivery system. Damage to associated parts of the machine.	Ensure that all beam delivery system components and parts are labelled to allow easy identification. Provide adequate instructions to minimize the risk of using incorrect parts or of incorrect assembly or adjustment. Incorporate interlocks to prevent incorrect parts or assembly.
Incorrect mounting of beam shaping optics.	Human error.	Laser radiation above AEL of Class 1 (by escaping the protected laser area, or exceeding the laser guard PEL).	Provide adequate instructions to minimize the risk of using incorrect parts or of incorrect assembly or adjustment. Conduct regular inspections.
Damage of beam shaping optics.	From collision with workpiece, overheated optics due to contamination or cooling water failure.	Laser radiation above AEL of Class 1 (by escaping the protected laser area, or exceeding the laser guard PEL).	Ensure that all beam delivery system components and parts are labelled to allow easy identification. Provide adequate instructions to minimize the risk of using incorrect parts or of incorrect assembly or adjustment. Incorporate interlocks or mechanical location keys to prevent the use of incorrect parts or incorrect assembly. Monitor the local temperature of vulnerable beam delivery components.

Table G.2 – Beam delivery systems using fibre optic cables

Use, reasonably foreseeable misuse or abuse	Possible failure mechanism	Hazard	Examples of risk reduction
Beam directed through beam switching device.	Beam switch "leaks" – laser beam partly or wholly guided to unexpected beam delivery system.	Laser radiation above AEL of Class 1 at unexpected beam delivery system.	Design the beam switching device to avoid this.
Beam directed through beam switching device.	Beam switch not in the correct position – laser beam partly or wholly guided to unexpected beam delivery system.	Laser radiation above AEL of Class 1 at the unexpected beam delivery system.	Monitor the beam switching device and interlock to ensure the beam switch components are in the correct positions.
Beam being coupled into fibre.	Damage (i.e. thermal) to coupling optics.	The coupling optical components or assemblies overheat to a degree where it damages or deforms, resulting in either leaking radiation or the production of errant beams.	The coupling optical components or assemblies to be designed to handle power passively. Interlock of the beam. Monitor component temperature and interlock into the control system.
Beam being coupled into fibre.	Damaged fibre at the input surface.	Fibre connector heats up to a degree where it deforms and laser radiation is not correctly coupled into the fibre.	Fibre connector designed to handle power passively. Introduce beam monitoring schemes and interlock into the control system.
Beam reflected from a work piece or target being coupled back into fibre.	Damaged fibre at the output surface and subsequent burn back or fusing of the fibre.	Fibre output connector heats up to a degree where it deforms and the fibre optic cable may be damaged.	Fibre connector designed to handle power passively. Introduce beam monitoring schemes and interlocks into the control system.
Beam in fibre optic cable.	Breakage due to mechanical forces on the fibre.	Laser radiation above AEL of Class 1 emitted from a broken fibre to the surrounding environment. Possible fire hazard.	Fibre to be put inside protective cover that protects from mechanical forces in the operating environment and potential misuse/abuse. Use the protective housing to limit excessive twist. Provide strain relief at the optical fibre terminations to minimize bending and twisting. Make the protective housing an active guard linked into the control system ~~(see IEC 60825-4)~~ . Monitor component temperature and interlock into the control system.

Use, reasonably foreseeable misuse or abuse	Possible failure mechanism	Hazard	Examples of risk reduction
With the laser beam being directed through the fibre optic, the fibre is subjected to repetitive flexing.	Breakage due to fatigue.	Laser radiation above AEL of Class 1 emitted from a broken fibre to the surrounding environment.	Design the protective housing to restrict the bending radius to prevent fibre breakage. Provide strain relief at the optical fibre terminations to minimize bending and twisting. Design a reinforced protective housing to be able to tolerate the laser radiation of the inner surface at the protective housing. Make the protective housing an active guard linked into the control system (see IEC 60825-4).
With the laser beam being directed through the fibre optic, the fibre is subjected to repetitive flexing.	Breakage due to other than mechanical forces (optical degrading, first pulses, etc.).	Laser radiation above AEL of Class 1 from a broken fibre to the surrounding environment.	The protective housing to be able to retain the laser radiation of the inner surface of the protective housing without breakthrough. Make the protective housing an active guard linked into the control system (see IEC 60825-4).
Unconnected fibre at the output of the fibre optic cable emitting laser radiation from the laser. Unconnected fibre at the input of the fibre optic cable emitting laser radiation from the laser.	Human error. Mechanical loosening of fixings due to incorrect assembly or vibrations, for example.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Interlock the fibre interface/connector. Ensure that the fixings and associated tools used to mount/dismount fibre interface are adequate. Minimize the requirement for the interface to be interfered with. Restrict this activity to service work carried out by skilled and authorized personnel with special training. Design a reinforced laser guard.
Incorrect mounting of beam shaping optics.	Human error.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Ensure design is adequately robust. Ensure instructions are sufficient for adjustments to be made securely. Recommend inspection intervals.
Damage of beam shaping optics.	From collision with workpiece, overheated optics due to contamination or cooling water failure.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Design considerations to include the complete laser guard. Provide collision protection or interlocks.

Use, reasonably foreseeable misuse or abuse	Possible failure mechanism	Hazard	Examples of risk reduction
Multiple fibres – mix of fibres.	Human error.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Orientate, mechanically interlock or clearly and indelibly mark fibre optic cables. Ensure instructions are clear and unambiguous. If the fibre optic cables transmit the laser beam to separate laser guarded enclosures, interlock the enclosure together with the fibre optic cable.

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INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Safety of laser products –
Part 4: Laser guards**

**Sécurité des appareils à laser –
Partie 4: Protecteurs pour laser**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SAFETY OF LASER PRODUCTS –

Part 4: Laser guards

FOREWORD

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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.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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.

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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 60825-1:2014, *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, *Safety of machinery – Laser processing machines – Laser safety requirements*

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

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

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, 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

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 (TEM_{00}), 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 a manufacturer 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 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**

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> credible and 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 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 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 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 if there 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) 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.

It is intended that a table of predetermined PELs for common combinations of lasers and guarding materials, together with suitable testing procedures, 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 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. 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 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 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 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 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. 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;
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.

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 may always be used.

A.2.4 Option 3: proprietary laser guard

A proprietary laser guard 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 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 4 Stipulation of angle of incidence is particularly important for laser guards exploiting interference layers to reflect impinging laser radiation.

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,

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

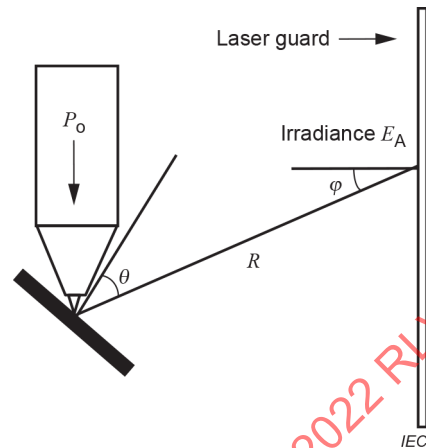


Figure B.1 – Calculation of diffuse reflections

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_{86} 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:

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

where ρ is the reflectivity of the workpiece surface.

CAUTION: Certain curved surfaces can increase the reflection hazard.

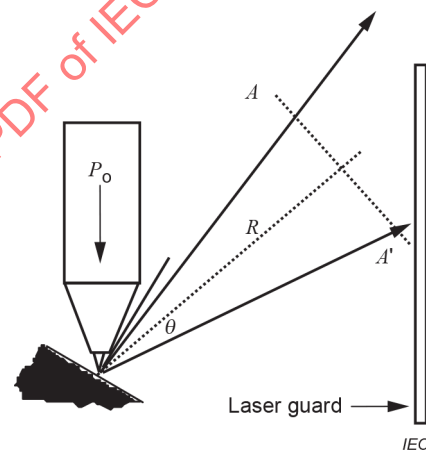


Figure B.2 – Calculation of specular reflections

B.3 Examples of assessment conditions

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

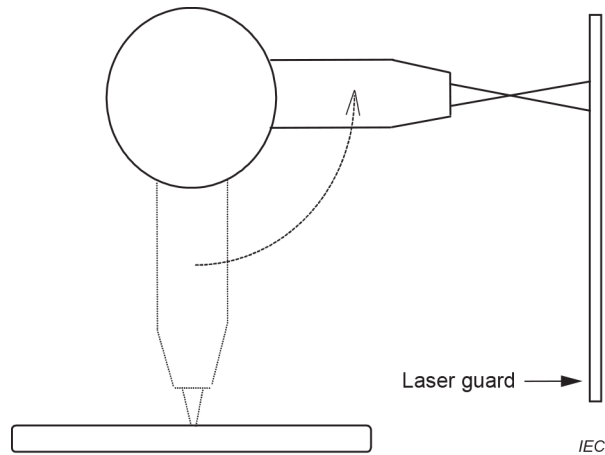


Figure B.3a – Software failure

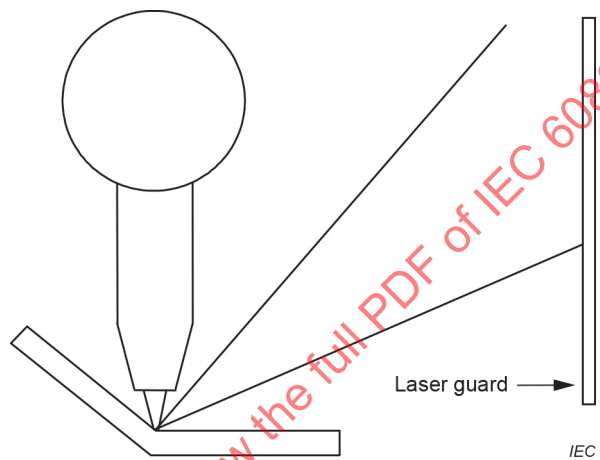


Figure B.3b – Workpiece bends or is inadequately clamped

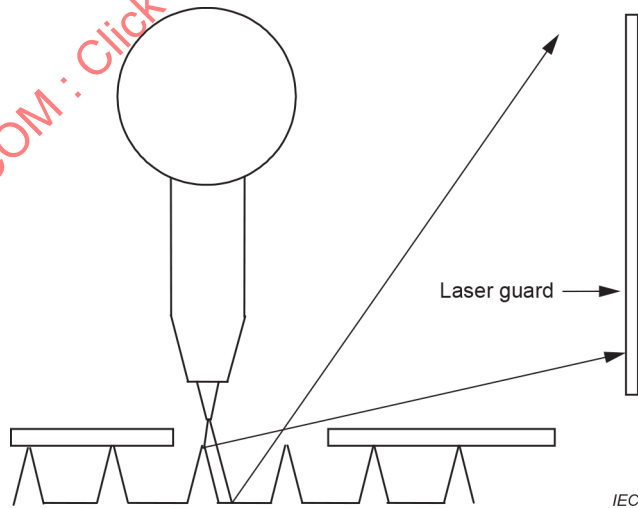


Figure B.3c – Workpiece missing

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

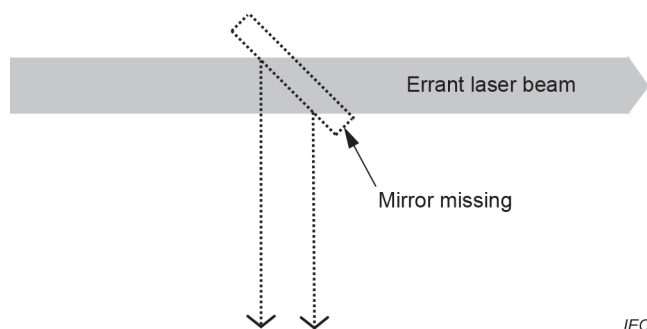


Figure B.4a – Laser is operated with turning mirror missing

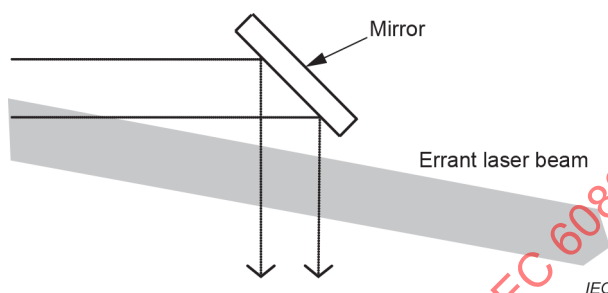


Figure B.4b – Beam displaced off mirror during alignment procedure

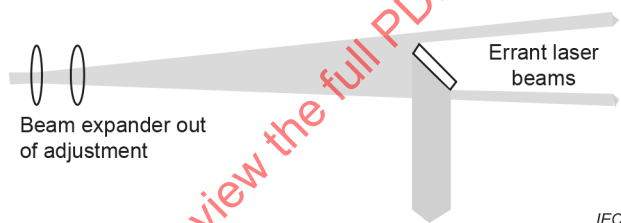


Figure B.4c – Beam expands beyond range of optics

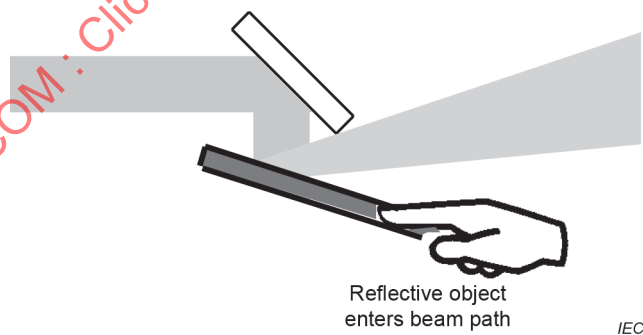


Figure B.4d – Reflective objects intercept laser beam

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

B.4 Exposure duration

B.4.1 Normal operation

The exposure of a guard to laser radiation during fault-free operation may comprise exposures to low levels of reflected, scattered and transmitted radiation which are repeated on each machine cycle. In this case, the assessed FEL for fault-free operation would encompass the variation in irradiance of the guard during the cycle, see Figure B.5, repeated for the maximum number of machine cycles within a safety maintenance inspection interval.

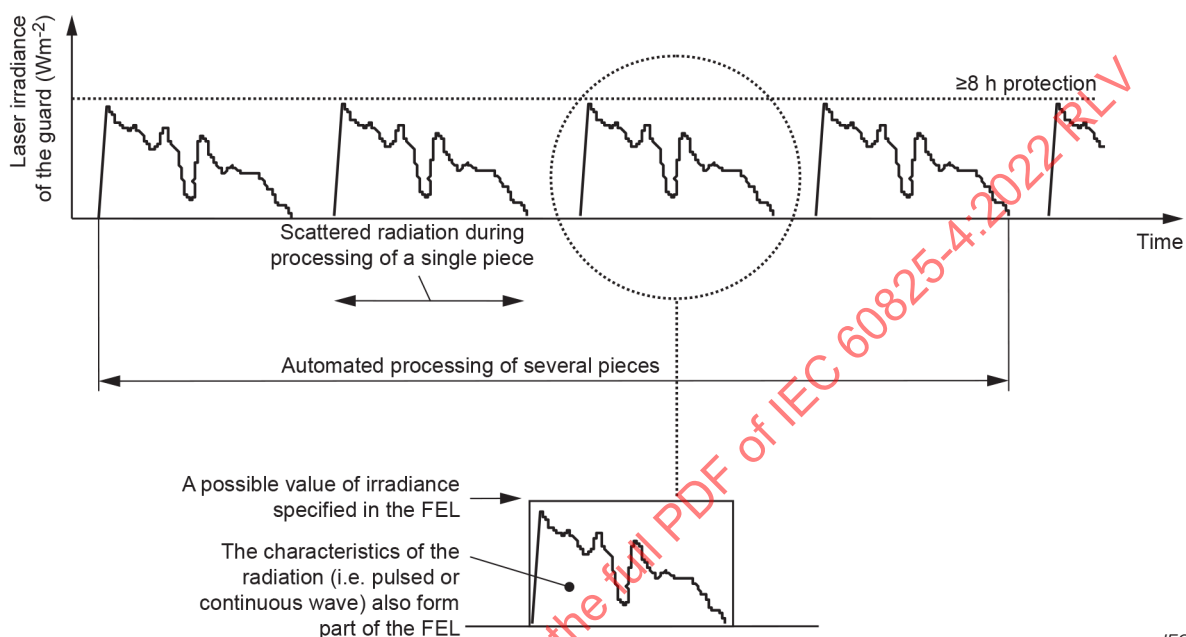


Figure B.5 – Illustration of laser guard exposure during repetitive machine operation

B.4.2 Fault conditions

A safety control system involving some form of machine monitoring can reduce the time for which the guard shall safely contain the radiation hazard under fault conditions. Two examples are given in Figure B.6.

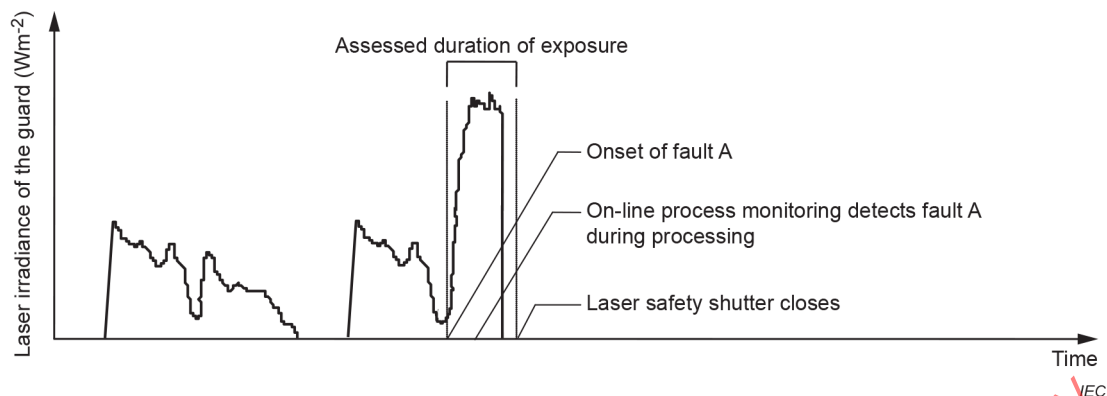


Figure B.6a – Shut-down with on-line machine safety monitoring

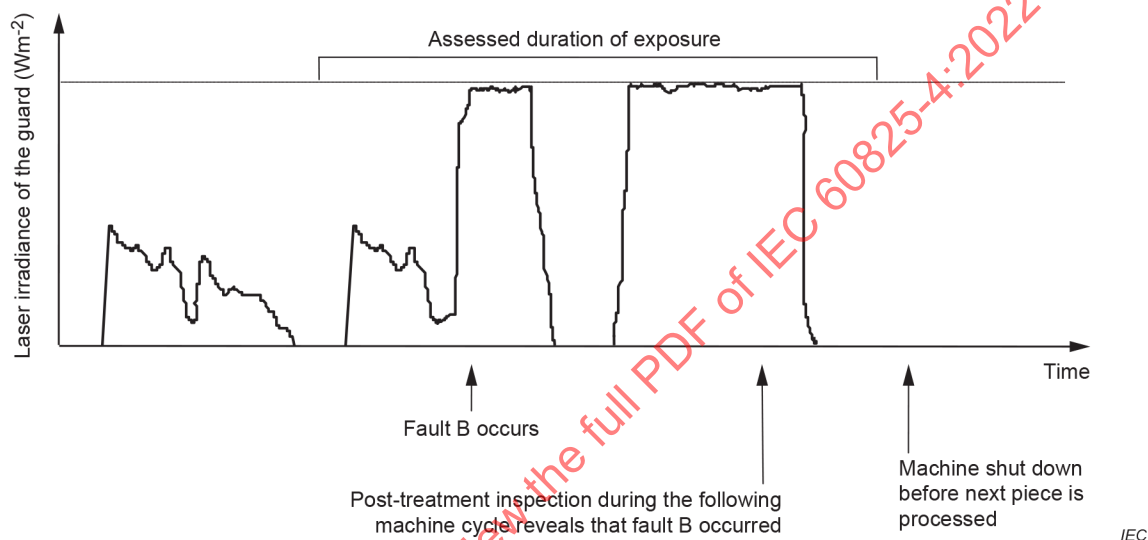


Figure B.6b – Shut-down with off-line machine safety monitoring

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.

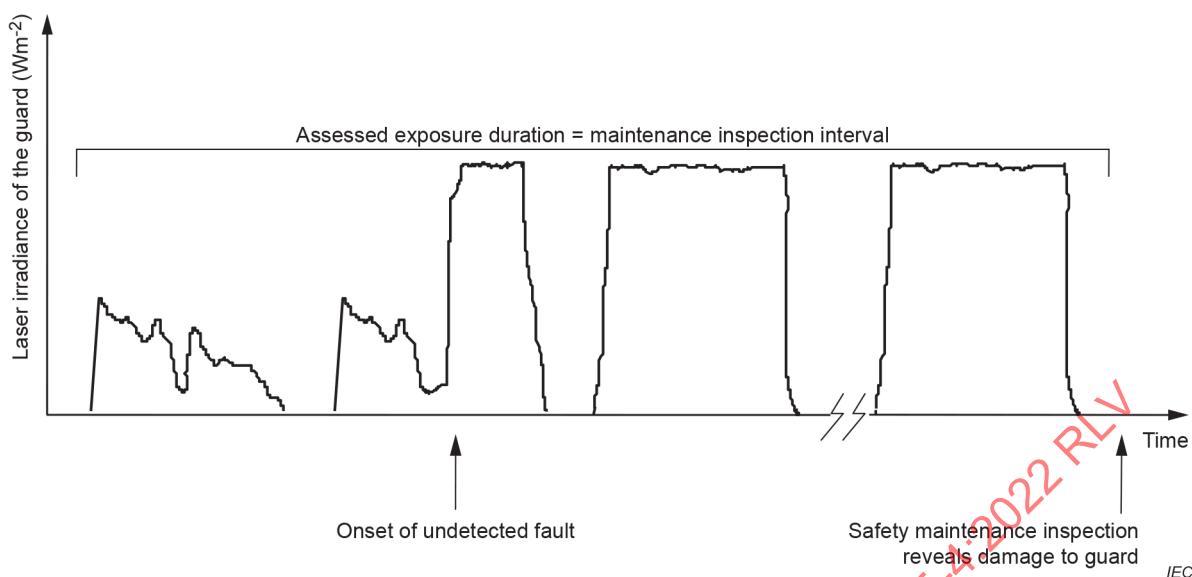


Figure B.7 – Assessed duration of exposure for a machine with no safety monitoring

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:

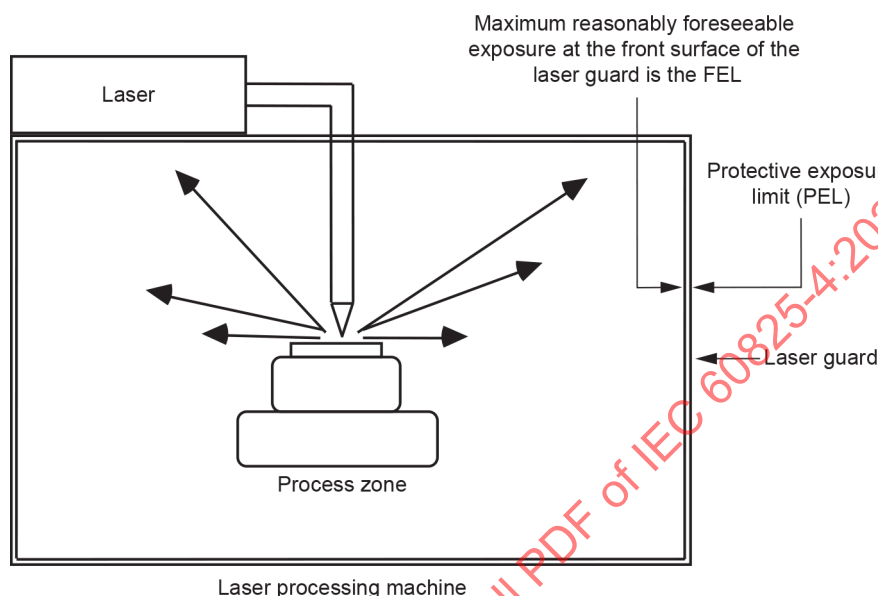
- the use of a pre-set laser-on time;
- the degree of control over fault conditions;
- provision of persons to supervise the condition of the guard (passive laser guards);
- provision of a hold-to-operate controller;
- degree of warning provided by the response of the guard to excessive laser exposure (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.

Annex C (informative)

Elaboration of defined terms

C.1 Distinction between FEL and PEL



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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.

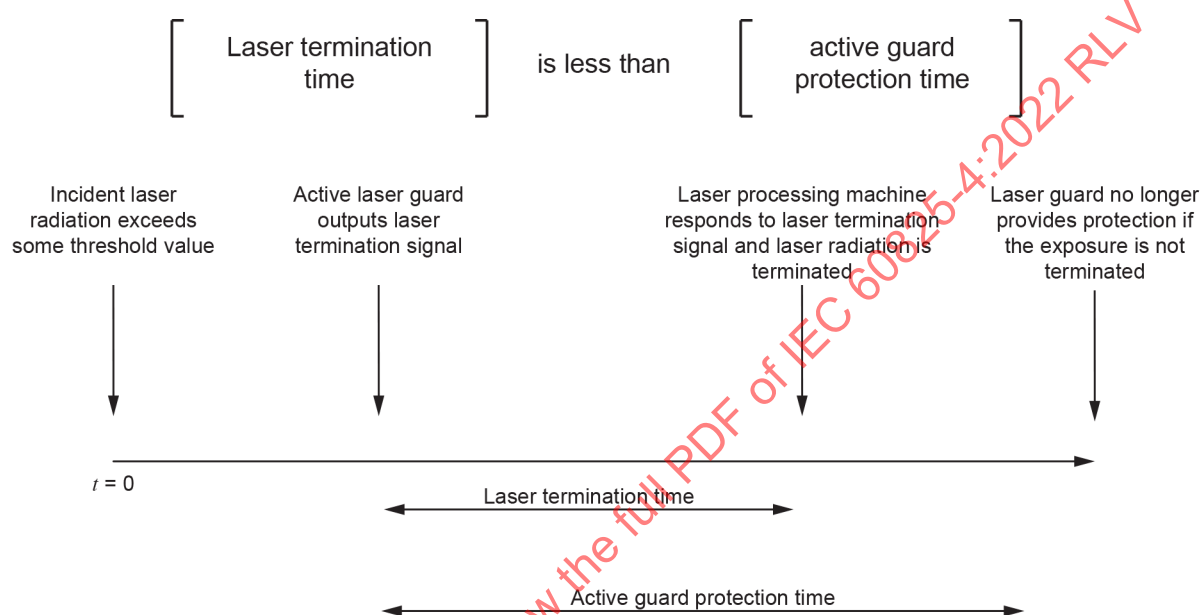
The PEL indicates the capability of a laser guard to protect against incident laser radiation. The manufacturer of the laser processing machine shall perform tests to confirm the adequacy of the laser guards. This can be accomplished by direct testing, or by determining the PEL of the guard, or by purchasing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



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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 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 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 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, 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. Testing conditions shall be accurately replicated, otherwise the resultant 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 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 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.

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

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

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 are highly dependent on sample preparation and experimental setup that affects the repeatability of the PEL and protection time measurements.

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), 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 shall be taken as the distance F_1 .

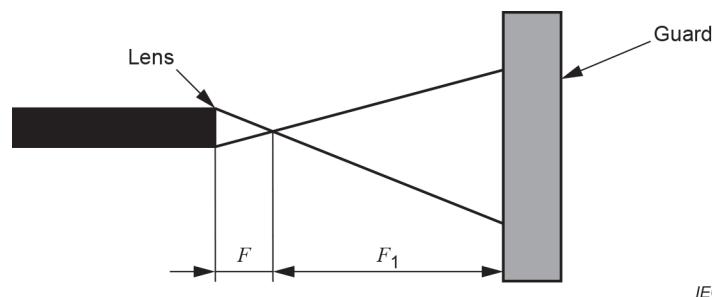


Figure D.1 – Simplified diagram of the test arrangement

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.

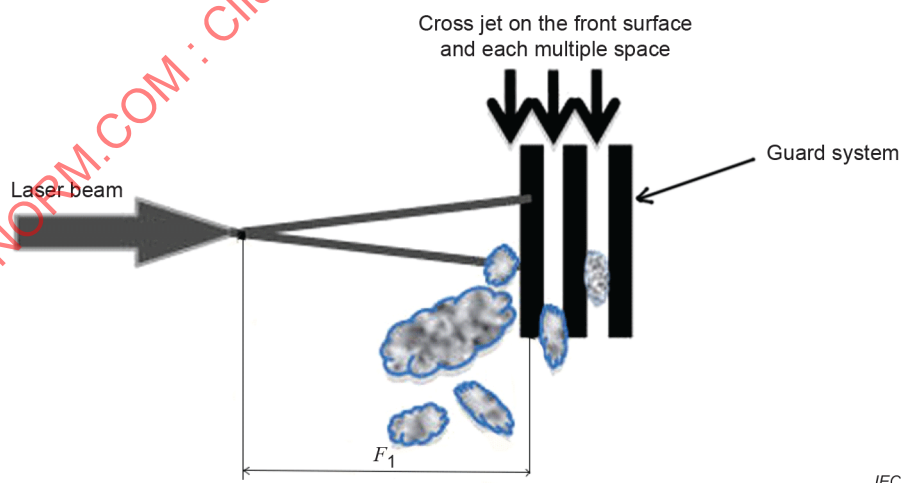


Figure D.2 – Simplified diagram of the ventilation for the guard under test

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 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 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) 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 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 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 parameter product (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 protection times and PEL together with any calculations and statistical analyses made.

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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) 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 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.

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 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 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 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 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 can give rise to optical misalignment. Attention 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;
- 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

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 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, 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.

F.6.2.3 Glass

Glass is unsuitable for guard manufacture due to its tendency to rupture. However, where a laser process is required to be observed and the material is likely to be exposed to high temperatures or abrasive action, a safety glass, which provides adequate protection from laser radiation (by internal absorption of the laser radiation within the material or suitable reflective optical coatings on the surface of the guard material), may be suitable. Methods for determining the suitability of such materials are given elsewhere in this document.

F.6.2.4 Plastics

Transparent plastic sheet materials may be used in laser guarding as an alternative to opaque materials especially where observation is required during the processing operation.

Plastic materials available for guarding purposes include polycarbonate and specially dyed acrylic sheet. It is essential that these materials are selected with appropriate optical protective properties for the wavelength and power of the laser source fitted to the laser processing machine.

The mechanical properties of many plastics are adversely affected by contaminants, by incorrect cold working and by continuous exposure to high temperatures or UV radiation. Continuous exposure to high temperature (polycarbonate: 135 °C, acrylic sheet: 90 °C) will cause softening and consequently lowering of both impact strength and other optical properties.

Any removal of the surface material may reduce the optical protective properties of the material at laser wavelengths and the provision of additional sacrificial mechanical protective layers should be considered.

Most plastics have an ability to hold an electrostatic charge. This can create a risk of electrostatic ignition of flammable materials and can also attract dust. This characteristic can be mitigated by the use of an anti-static preparation.

F.6.2.5 Other materials

Concrete block work may be an effective material for some guard construction and is frequently used for large CO₂ laser processing machine enclosures.

F.6.3 Supports

Guards may be fastened to independent supports or to the machinery itself. The number and spacing of the fixings should be adequate to ensure stability and rigidity of the guard.

Where necessary, there should be clearances around the guard for cleaning and debris removal, etc., provided that this clearance does not allow access to the hazard zones.

F.6.4 Cover plates

Removable panels or cover plates may be incorporated into guards to provide easy access or improved visibility. They should be treated as part of the guarding system and may be considered as either fixed or interlocking guards depending upon the process requirements.

F.6.5 Anthropometrical considerations

Guards should be designed and constructed with the object of preventing any part of the body from reaching the danger zone. They should take into account the physical characteristics of the people involved and in particular their ability to reach through openings and over or around barriers used as guards. The best approximation of currently available data for human body measurements (anthropometrical data) is given in ISO/TR 7250-2.

F.7 Other safety devices

F.7.1 Trip devices

A trip device is a device which causes working machinery to stop, or assume an otherwise safe condition, to prevent injury when a person approaches the danger zone beyond a safe limit. The device will be required to keep the machine in this condition while the person remains within the danger zone unless other means of fulfilling this function are provided.

A trip device should be designed to ensure that an approach to a hazard or danger zone beyond a safe limit causes the device to operate and the hazard to be terminated before injury can be inflicted.

A trip device should be designed so that after it has been operated it may be reset automatically or manually; restarting should then be by means of the normal start actuator. The trip device operation should not be impaired by any extraneous influences.

F.7.2 Electro-sensitive protection equipment

Electro-sensitive protective equipment is sometimes referred to as intangible barriers and operates as trip devices on the principle of detecting the approach of persons or parts of persons into danger zones, etc. The means of detection can be active opto-electronic, active opto-electronic responsive to diffuse reflection, passive infra-red, capacitance, inductive, microwave, or visual intrusion. The effectiveness of the complete installation will depend not only on the integrity of the electro-sensitive protective equipment, but also on the electrical and mechanical integrity of the remaining installation, and the location of the electro-sensitive protective equipment sensing device relative to the danger zone.

F.7.3 Control systems (keys, pressure-sensitive mats, light curtains)

F.7.3.1 Captive-key systems

Generally a captive-key interlocking device is a combination of an electrical switch with a mechanical key operated lock secured to the fixed part of the machine. The operating key is held captive on the moveable part of the guard. To open the guard, the key is turned, which puts the switch into the "off" position and releases the key from the lock so that the guard can be opened.

Some captive-key systems are made up of trapped-key interlocking systems. In a trapped-key interlocking system the guard lock and a switch that incorporates a lock, are separate as opposed to being combined into a single unit. The essential feature of the system is that the removable key is trapped either in the guard lock, or in the switch lock. The lock of the guard is arranged so that the key can be released only when the guard has been closed and locked. This allows transfer of the key from the guard to the switch lock. Closing the switch traps the key so that it cannot be removed when the switch is in the "on" position.

F.7.3.2 Pressure-sensitive mats

Pressure-sensitive mats and floors contain sensors that operate when a person or object applies pressure to the mat or floor. They should be subject to periodic maintenance and inspection, since by their nature, pressure-sensitive mats are exposed to potential damage that can result in failure.

The dimension of mats should take into account a person's speed of approach, length of stride and the overall response time of the protective device. Care should be taken that access cannot be gained without actuation of the mat or floor. Account should be taken of dead surfaces within the mat especially around their edges, when a number of mats are used together. Guidance on the application of pressure-sensitive mats may be found in IEC TS 62046. A pressure-sensitive mat may be appropriate to indicate the presence of a person inside the machinery and/or stop the machinery if required.

F.7.3.3 Light curtains

Light curtains often operate on the principle of the detection of an obstruction in the path taken by a beam or beams of light. The intangible barrier operated by this system may consist of a single light beam device or a number of light beam devices arranged as a curtain. The curtain also may be created by a scanning light beam or a number of fixed beams. The light may be visible or invisible. The requirements for the design and performance of these devices for protective purposes are specified in IEC 61496-2.

F.8 Interlocking considerations

F.8.1 Functions of interlocks

An interlock provides the connection between a guard and the control system of the laser processing machine to which the guard is fitted. The interlock and the guard with which it operates should be designed, installed and adjusted so that:

- a) until the guard is closed the interlock prevents laser emission by interrupting the laser beam either by means of a beam attenuator or by removal of power from the laser;
- b) either the guard remains locked closed until the risk of injury from the hazard has been removed, or opening the guard causes the hazard to be eliminated before access is possible.

Care should be taken to ensure that actuation of an interlock installed to protect against one hazard does not create a different hazard.

F.8.2 Interlocking media

The four media most commonly encountered in interlocking are electrical, mechanical, hydraulic and pneumatic. Electrical interlocking, particularly in control systems, is the most common. The principles of interlocking apply equally to all media. Each has advantages and disadvantages, and the choice of interlocking medium will depend on the type of laser processing machine and the method of access to hazard zones.

Some interlocking systems have more than one control channel, e.g. dual control systems. It is often advantageous to design these systems so that similar failures in both channels from the same cause (common cause failures) are minimized.

F.8.3 Common interlocking methods

F.8.3.1 Guard locking power interlocking

With guard locking power interlocking, the power medium is interrupted directly by a single device which is arranged so that:

- a) the device physically prevents the guard from being opened while the power medium is uninterrupted;
- b) the device is physically held by the guard in the position which is interrupting the power medium when the guard is open.

F.8.3.2 Interlocking guard power interlocking

With interlocking guard power interlocking, the power medium is interrupted directly by a single device that is automatically operated by movement of the guard. The guard and device should have been arranged so that the power medium is interrupted as the guard is opened, and remains interrupted while the guard is in any position other than closed.

F.8.3.3 Dual-control system interlocking with cross monitoring

In dual-control system interlocking with cross-monitoring, there are two separate power interrupting devices, each capable of interrupting the power medium. The devices should be arranged in series, so that the operation of either will result in the interruption of the power medium. These are operated by individual devices actuated by the guard.

The power interrupting devices should have been monitored so that the failure of either their control systems or the interrupting devices themselves, to respond to the control system signal will be immediately detected and a further operating cycle of the laser processing machine prevented. The circuitry of each power interrupting device, including its operating device, should be kept physically separated as far as is practicable, to reduce the probability of the interlocking system failing to danger as a result of common cause failures.

F.8.3.4 Dual-control system interlocking without cross monitoring

Dual-control system interlocking without cross-monitoring follows the same principles as those described above but without the facility to monitor automatically the correct functioning of the two power interrupting devices.

In the absence of automatic monitoring, it is possible for either interlocking channel to fail to danger and for the fault to remain undetected, which then reduces the integrity of the system to that of single-control system interlocking. For dual-control system interlocking without cross-monitoring to function effectively, however, it is important that a regular check is carried out to ensure that both channels are working correctly. The frequency of checking will depend on the reliability of the components used and the conditions under which the interlocking system is operating.

F.8.3.5 Single channel system interlocking

Single-control system interlocking employs an interlocking device which indirectly interrupts the power medium by operating a single power interrupting device via a control system. It does not have a high level of integrity because of the greater possibility of single component failure in the system causing the whole system to fail to danger. The system, therefore, should have been designed and installed using the minimum number of components.

The system should be inspected and tested regularly and any worn or damaged components replaced or repaired.

F.8.4 Failures of interlocking systems

F.8.4.1 General

Interlocking systems should be designed to minimize the possibility of the interlocking system as a whole to fail to danger.

As power supplies frequently fail, components relying on the power supply for their functioning should be installed so that power loss minimizes failure to danger of the system as a whole.

F.8.4.2 Types of failure

The most common types of failure from which an interlocking system may suffer are:

- a) failure, interruption or variation of externally supplied power;
- b) open circuits in electrical systems;
- c) mechanical failure, e.g. breakage or seizure;
- d) malfunction due to electrical environment, i.e. mains borne or radiated disturbance;
- e) malfunction due to vibration;

- f) malfunction due to power supply contamination;
- g) earth faults, i.e. accidental connection of a conductor to earth causing, for example, unexpected start-up or failure to stop;
- h) other single component failures leading to change of characteristic or loss of function;
- i) cross-connection failures causing, for example, unexpected start-up or failure to stop.

Measures can be taken to minimize the consequences of single failures in interlocking systems. These may include the use of additional control or monitoring circuits. However, the system as a whole can still fail due to multiple undetected failures, e.g. common cause failures or undetected failures followed by further failure.

Common cause failures may typically result from:

- j) external environment e.g. contamination from dust, electrical disturbances, extreme temperatures, vibration or radiation;
- k) components from a substandard batch being used in each channel;
- l) damage due to localized fire or impact.

F.8.5 Security of interlocking systems

The security of an interlocking system can be improved by avoiding motives for its defeat and/or by making defeat more difficult.

The design of the safeguarding system should have taken full account of the need for human intervention in the machine during any phase of its life.

Ways in which defeat may be made more difficult include:

- a) the use of interlocking devices or systems which are coded;
- b) physical obstruction or shielding of the interlocking device while the guard is open.

F.8.6 Integrity of interlocking systems

The integrity of an interlocking system will depend not only on the direct effects of failures or defeats, but also whether or not those failures or defeats lead to damage to other components or interconnections within the system. Therefore, an important consideration should be circuit protection.

Other basic criteria for improving the integrity of an interlocking system include:

- a) correct installation;
- b) good quality, high integrity components, protected to withstand the environment (including possible reflections of laser energy) and rated for the duty they have to perform;
- c) minimizing by design, manufacture and correct installation, the probability of an earth fault occurring;
- d) minimizing failure to danger;
- e) minimizing defeat.

F.8.7 Choice of interlocking system

Interlocking systems should be selected for particular applications taking account of:

- a) the frequency with which approach to the danger zone is required;
- b) the probability and severity of injury should the interlocking system fail;
- c) the resources required to reduce the risk of injury.

F.8.8 Electrical considerations

Electrical control systems can fail in ways that could result in hazardous situations. Particular attention should be paid to minimizing the probability of this occurring. IEC 60204-1 gives guidance.

Devices should be selected only from those where the performance, as stated by the manufacturer, is suitable for the specific safety application. The following performance data should be considered:

- a) resistance to environmental conditions;
- b) life evaluation;
- c) duty rating;
- d) reliability.

Proximity switches which rely solely on the presence or absence of metal for their actuation are not generally suitable for interlocking duties because they can be easily defeated. However with careful design, these devices can be incorporated into difficult to reach or small assemblies. Extreme care needs to be taken to prevent the devices being defeated and suitable redundancy used to prevent common cause failures resulting in an overall failure to danger.

F.8.9 Mechanical considerations

F.8.9.1 Interlocking devices

Mechanical devices for connecting guard movement with the machine power or control system can take various forms but will generally perform the same function. They will usually be arranged so that operation of the guard and the machine can only be carried out in a correct safe sequence.

F.8.9.2 Mechanical interlocking methods

Unlike electrical, hydraulic or pneumatic systems, it is unusual for mechanical systems to be other than a single-control system.

The basic elements of single-control system interlocking are:

- a) the actuating device operated by the guard;
- b) interposed mechanical linkages, if any;
- c) the device for preventing the emission of laser radiation or preventing the power to any other hazard.

Reducing the number of interposed linkages reduces the probability of the system failing to danger.

F.8.10 Pneumatic and hydraulic considerations

F.8.10.1 Interlocking devices

Devices used for interfacing guard movement include:

- a) cam-operated valves;
- b) captive-key valves; tap-key control of pneumatic valves;
- c) pneumatic jet detection valves;
- d) pneumatically or hydraulically operated locks.

When valves are selected for safeguarding applications, the valve operating parameters (pressure, temperature, etc.) and reliability should be suitable for the environment and the duty envisaged.

F.8.10.2 Pneumatic or hydraulic interlocking methods

In general, interlocking methods as described in F.8.3 are applicable. These methods include:

- a) single-control system interlocking;
- b) dual-control system interlocking with or without cross-monitoring;
- c) power interlocking.

All piping, hoses, etc., between control valves and interlocks should be suitable for the fluid and operating environment, correctly sized and rated for maximum flow and pressure and, where necessary, further effectively protected and securely mounted. Pipework fittings should be selected to ensure their integrity does not compromise the overall integrity of the interlocking system.

F.9 Environmental considerations

F.9.1 Environment

The selection of a safeguard should take into consideration the environment in which it is used. In a hostile environment it should be capable of withstanding the conditions likely to be experienced and should not of itself create a hazard as a result of that environment.

F.9.2 Corrosion

If a guard is likely to be exposed to a corrosion risk, special measures should be taken. The use of corrosion-resistant materials or corrosion-resistant surface coatings should be considered.

F.9.3 Hygiene and guard design

Guards used in certain industries, notably for processing of food or pharmaceuticals, should be so designed that they are not only safe to use but can be readily cleaned. Materials used for safeguards should be non-toxic, non-absorbent, shatterproof and readily cleanable and be unaffected by the material being processed or by cleaning or sterilizing agents.

F.9.4 Mist, fumes and dust

Where the process gives rise to hazardous or objectionable levels of vapours, fumes or dust, containment or suitable extraction equipment should be provided. The levels of exposure to vapours, fume or dust should conform to the occupational exposure limits and occupational exposure standards for local control of substances hazardous to health.

F.9.5 Noise

Consideration should be given to noise reduction when designing safety enclosures and guards. It is often possible for guard enclosures to be designed to serve a dual purpose of protecting against laser radiation hazards together with mechanical hazards and reducing noise emissions. Guards should not add to the noise levels because of poor design or fixing.

F.10 Installation consideration – Environmental factors – Services

F.10.1 Lighting

When considering the lighting in relation to the laser processing machine the following aspects affect the safety of the people involved:

- a) the direction and intensity of the light;
- b) the contrast between the background and local illumination;
- c) the colour of the light source;
- d) reflection, glare and shadows;
- e) the visual wavelength transmission characteristics of viewing windows.

F.10.2 Cables and pipes

Service pipes and cables should either be placed outside of the process zone or, when this is not possible, provided with covers of adequate strength and capable of tolerating laser radiation exposure under foreseeable fault conditions.

F.11 Maintenance and service considerations

F.11.1 Operational maintenance of safeguards

The maintenance of safeguards, once they are taken into use, is essential to their continued effectiveness.

There should be regular inspection of safeguards to ensure that the requisite standard of safety is maintained. The routine inspection of safeguards should be made as part of a planned maintenance programme.

F.11.2 Properties of laser guard materials

By way of illustration, Figure F.1 to Figure F.22 provide some experimentally-determined limits of laser beam power and beam diameter for burn-through times of 10 s or 100 s for various metal sheets: the sheets were mounted vertically and the front surface painted black; and the laser beam was horizontal. Burn-through time is the time taken for the laser beam to remove the material in its path (e.g. by melting, vaporization, ablation) and the data should be taken only as a guide, since values can vary widely depending on the beam parameters (including wavelength and beam profile) and the condition of the guard surface.

The performance of a laser guard may also be dependent on its particular design and application; and it is recommended that the suitability of a laser guard design is verified by adequate performance testing.

Some examples of various guard materials are shown in Figure F.1 to Figure F.22.

Figure F.1 – 1 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.2 – 1 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.3 – 2 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.4 – 2 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.5 – 3 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.6 – 3 mm thick zinc coated steel sheet for CW CO₂ laser

Figure F.7 – 2 mm thick aluminium sheet for CW CO₂ laser

Figure F.8 – 2 mm thick aluminium sheet for CW CO₂ laser

Figure F.9 – 1 mm thick stainless steel sheet for CW CO₂ laser

Figure F.10 – 1 mm thick stainless steel sheet for CW CO₂ laser

Figure F.11 – 6 mm thick polycarbonate sheet for CW CO₂ laser

Figure F.12 – 6 mm thick polycarbonate sheet for CW CO₂ laser

Figure F.13 – 1 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.14 – 1 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.15 – 2 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.16 – 2 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.17 – 3 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.18 – 3 mm thick zinc coated steel sheet for CW Nd:YAG laser

Figure F.19 – 2 mm thick aluminium steel sheet for CW Nd:YAG laser

Figure F.20 – 2 mm thick aluminium steel sheet for CW Nd:YAG laser

Figure F.21 – 1 mm thick stainless steel sheet for CW Nd:YAG laser

Figure F.22 – 1 mm thick stainless steel sheet for CW Nd:YAG laser

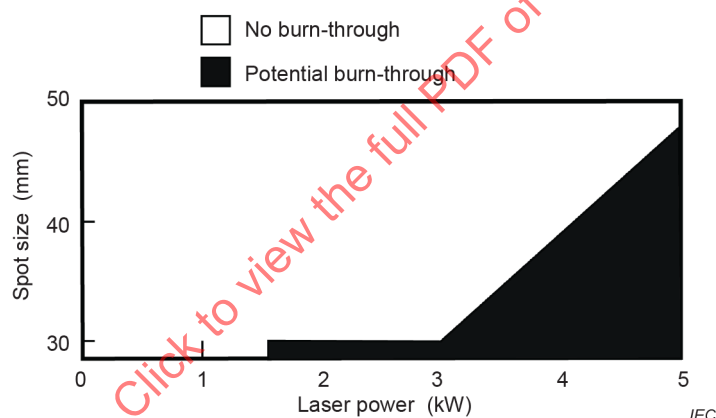


Figure F.1 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

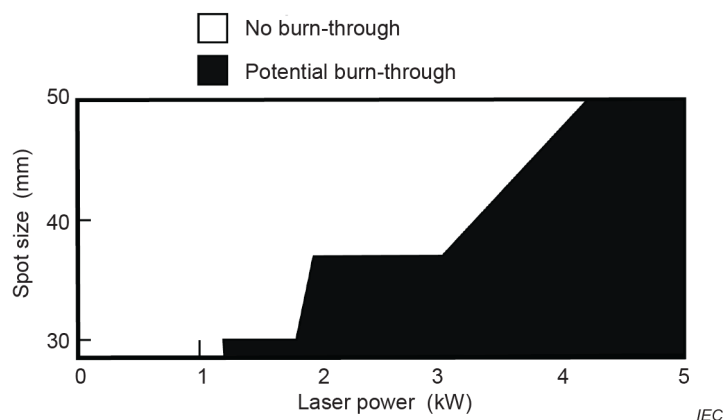


Figure F.2 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

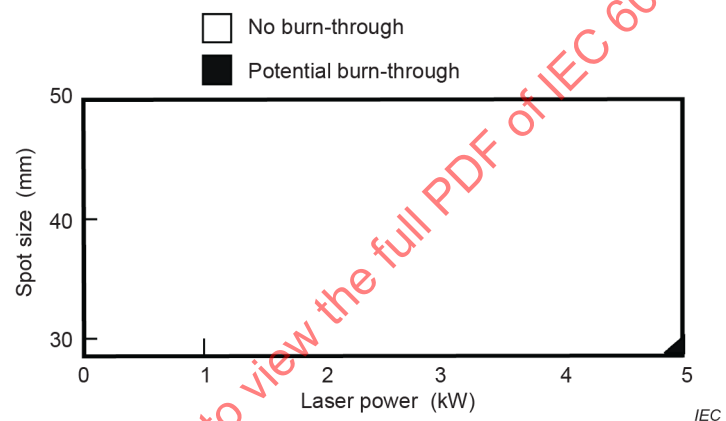


Figure F.3 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

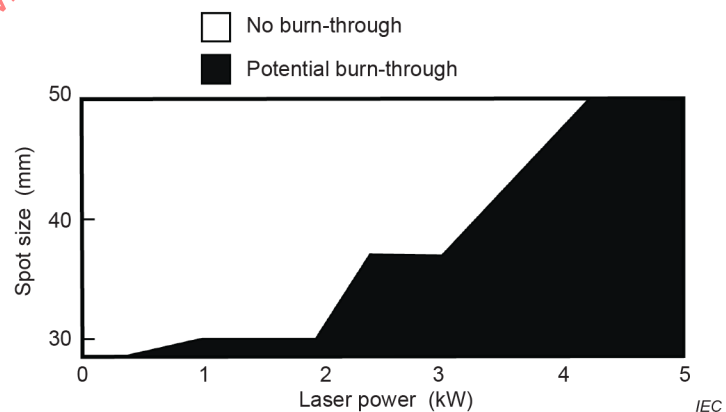


Figure F.4 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

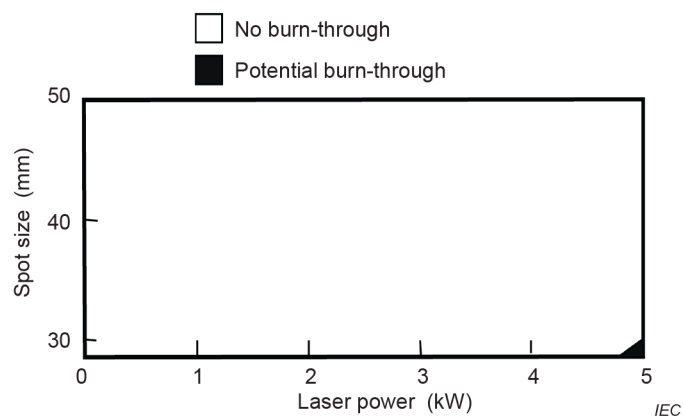


Figure F.5 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

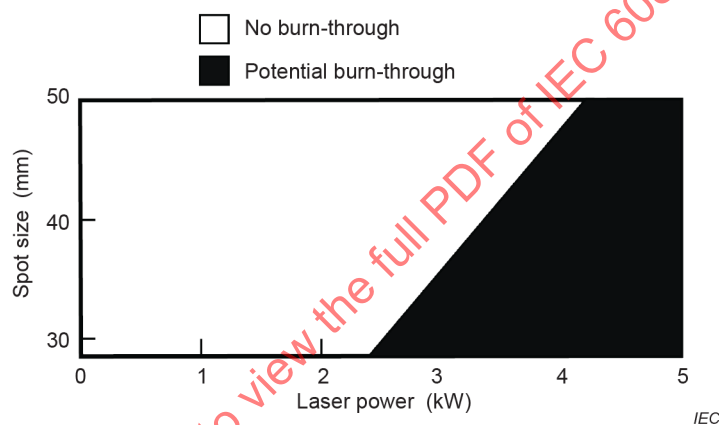


Figure F.6 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

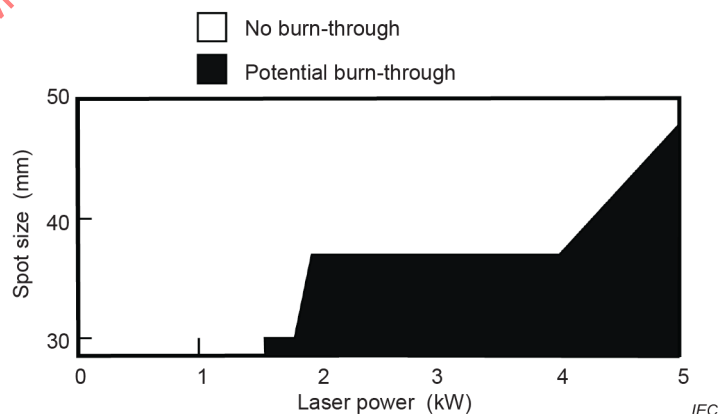


Figure F.7 – Damage resistance of 2 mm thick aluminium sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

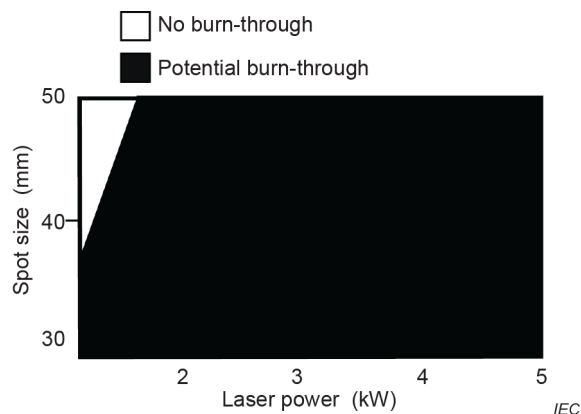


Figure F.8 – Damage resistance of 2 mm thick aluminium sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

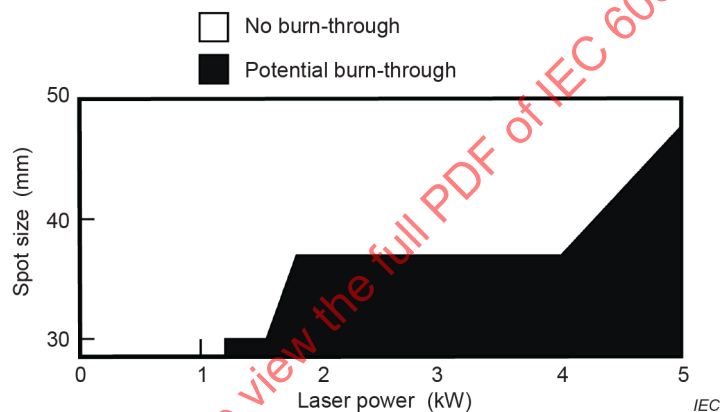


Figure F.9 – Damage resistance of 1 mm thick stainless steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

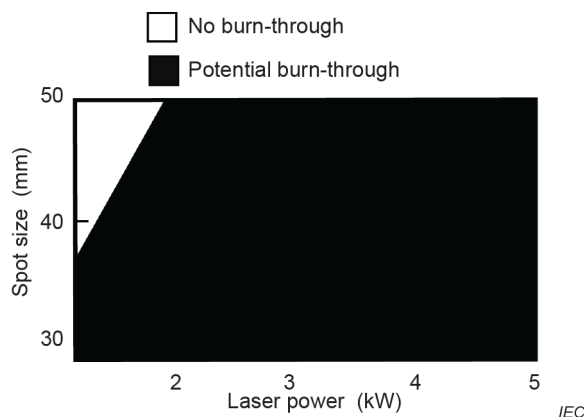


Figure F.10 – Damage resistance of 1 mm thick stainless steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

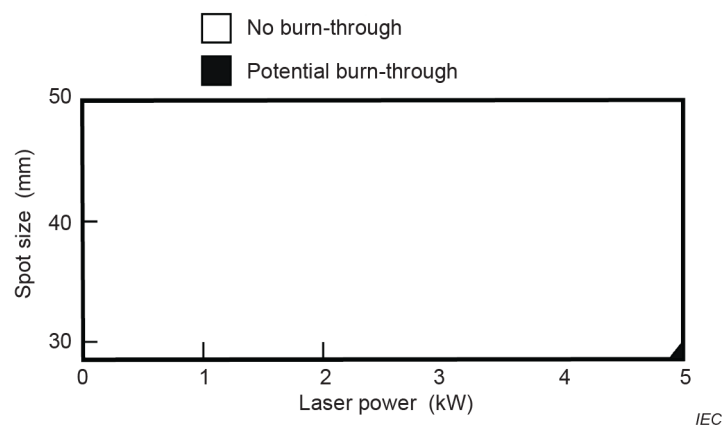


Figure F.11 – Damage resistance of 6 mm thick polycarbonate sheet derived from 10 s exposure to a defocused beam during experiments using a CW CO₂ laser

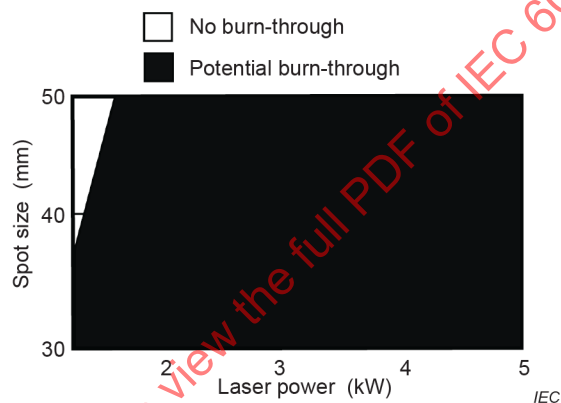


Figure F.12 – Damage resistance of 6 mm thick polycarbonate sheet derived from 100 s exposure to a defocused beam during experiments using a CW CO₂ laser

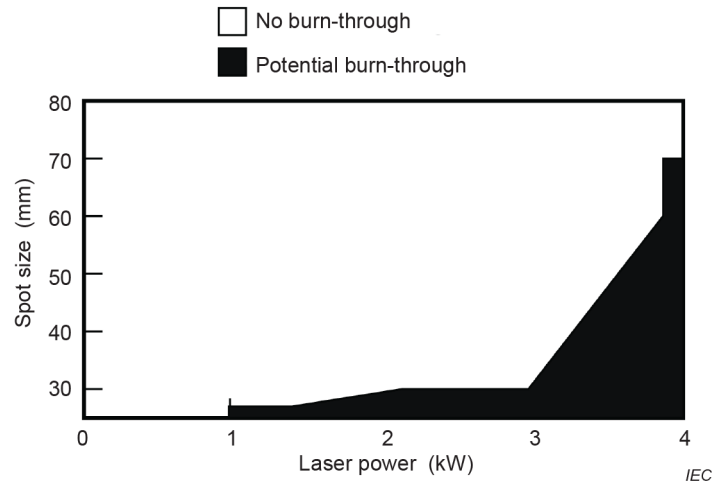


Figure F.13 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

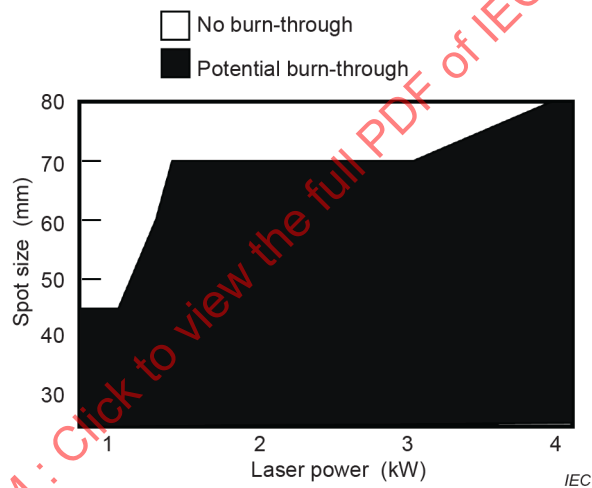


Figure F.14 – Damage resistance of 1 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

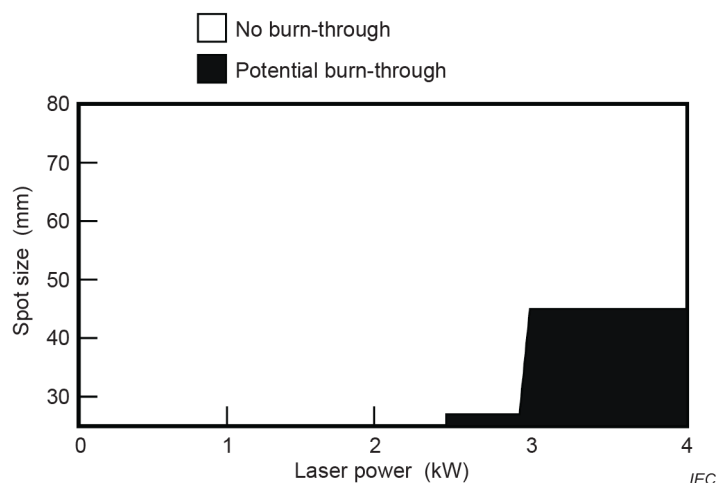


Figure F.15 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

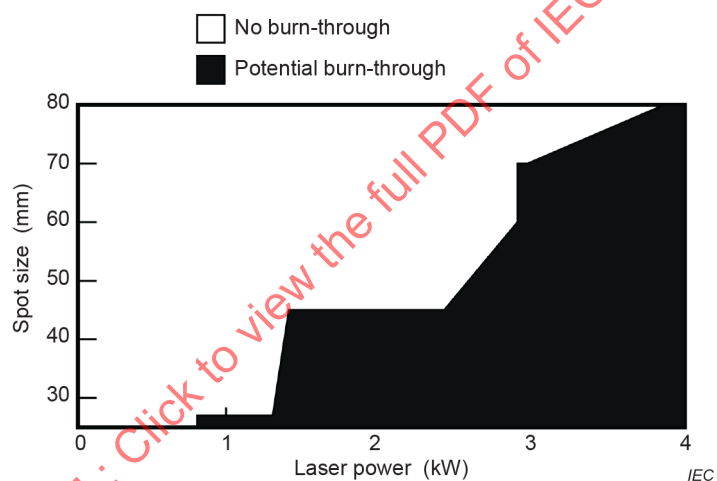


Figure F.16 – Damage resistance of 2 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

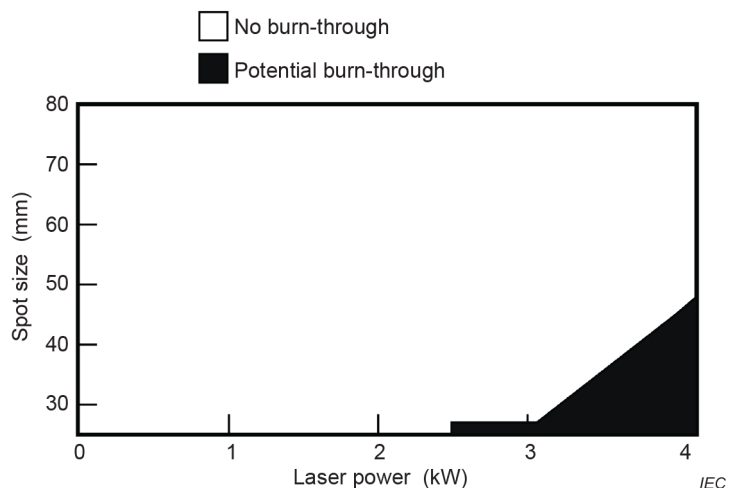


Figure F.17 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

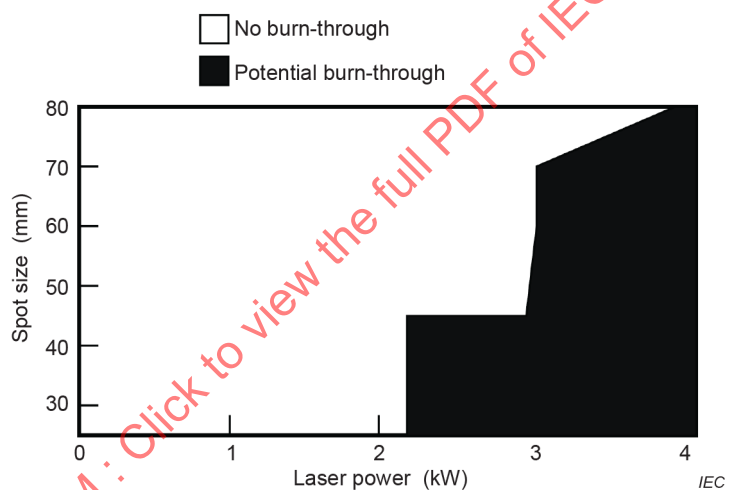


Figure F.18 – Damage resistance of 3 mm thick zinc coated steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

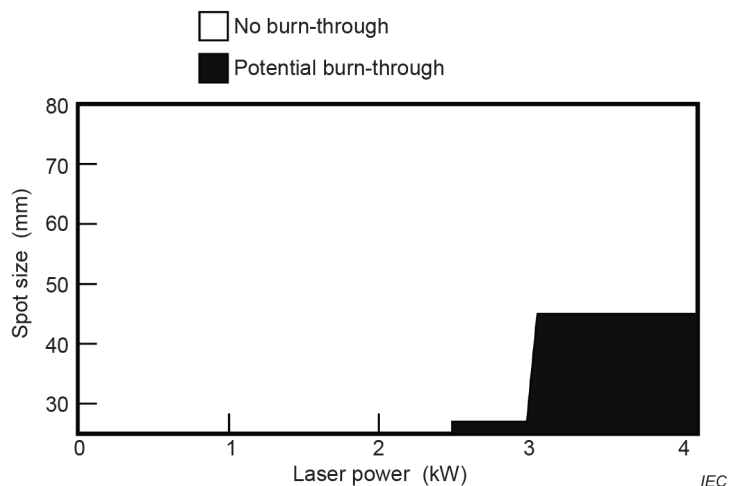


Figure F.19 – Damage resistance of 2 mm thick aluminium sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

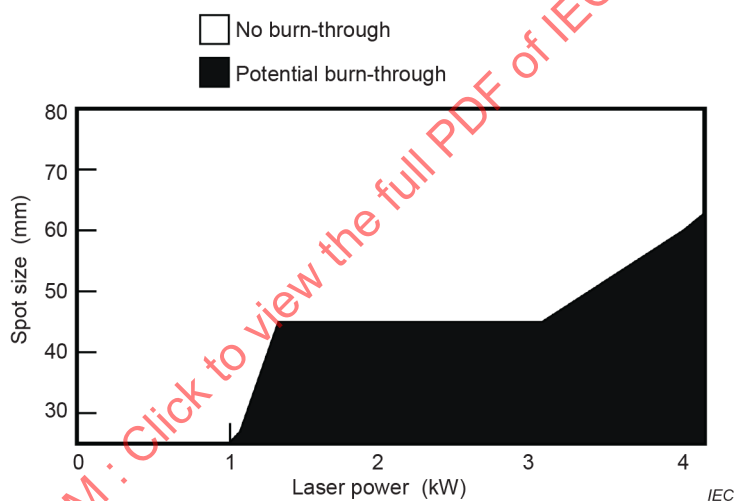


Figure F.20 – Damage resistance of 2 mm thick aluminium sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

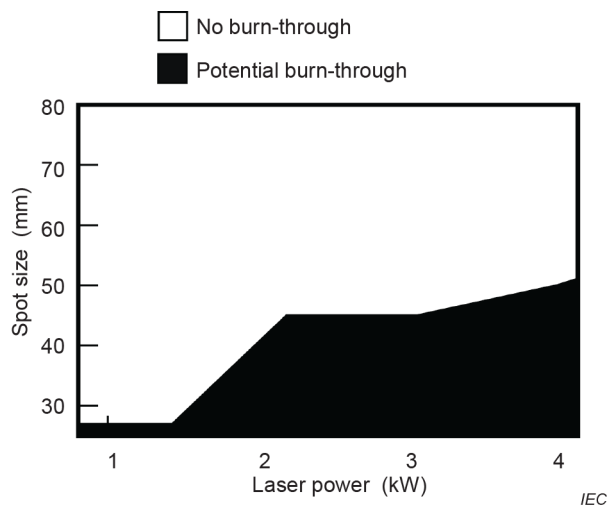


Figure F.21 – Damage resistance of 1 mm thick stainless steel sheet derived from 10 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

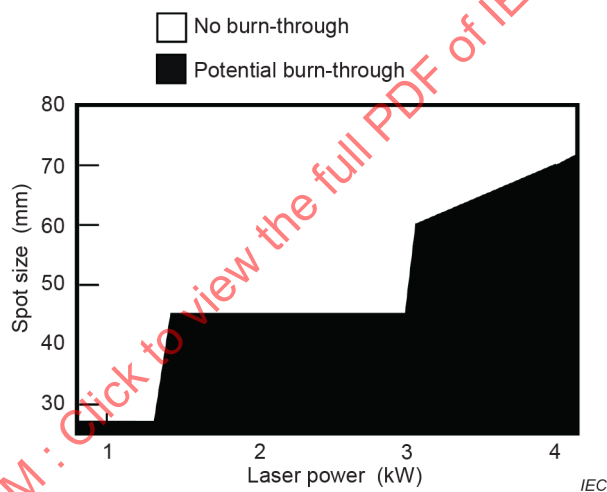


Figure F.22 – Damage resistance of 1 mm thick stainless steel sheet derived from 100 s exposure to a defocused beam during experiments using a CW Nd:YAG laser

Annex G (normative)

Guided beam delivery systems

G.1 General

Annex G addresses the arrangement, installation and use of guided beam delivery systems. Laser beams can be propagated through air, gas or vacuum, whether enclosed or not (free space), and through fibre optic cables in laser processing machine applications.

Annex G applies to the protective measures implemented to protect personnel against laser radiation hazards for guided beam delivery systems after the output coupler and/or the protective housing of the laser product (the requirements of which are specified in IEC 60825-1). Annex G is intended to complement the requirements applicable to the laser process enclosure (which are specified in this document and in ISO 11553-1). Annex G also provides methods for assessing the risks (including reasonably foreseeable use, abuse and misuse) and provides examples of control measures to meet the normative requirements of IEC 60825-1 and this document.

Annex G is not applicable to

- a) embedded beam delivery components and systems inside the protective housing of the laser radiation generator;
- b) communications applications;
- c) medical applications.

G.2 General requirements

G.2.1 General considerations

The risks associated with the hazards relevant to the beam delivery systems shall be assessed as part of the overall requirements for risk assessment of the machine. The principles for risk assessment given in ISO 12100 shall be used in carrying out this assessment. This assessment shall determine the acceptable level of risk and the necessary protective measures for persons who can be exposed to those hazards, while maintaining an acceptable level of performance of the machine.

Hazards can result from, but are not limited to, the following causes:

- a) failures, faults or damage in the protective housing or other mechanical protective measures incorporated in the beam delivery system resulting in the inadvertent emission of laser radiation from the protective housing;
- b) failures or faults in the beam path components resulting in damage to the protective housing or other protective devices;
- c) failures or faults in the associated equipment or controls resulting in injury or malfunction or failure of the safety functions of the laser processing machine;
- d) failures or faults from reasonably foreseeable misuse or abuse resulting in the inadvertent emission of laser radiation from the protective housings.

The engineering and administrative controls adopted are a combination of the measures incorporated at the design stage and include those instructions to be followed by the user.

Design shall be the first consideration in the reduction of risks. Where this is not sufficient to eliminate risks to a negligible level, additional safeguarding and safe working procedures shall be considered.

NOTE Examples of risk assessments and potential solutions for risk reduction measures are shown in Clause G.5.

G.2.2 Protective housing

The requirements for protective housing are specified in 6.2.1 and 6.2.2 of IEC 60825-1:2014.

G.2.3 Access panels and safety interlocks for beam delivery systems using free space transmission

The requirements for access panels and safety interlocks are specified in IEC 60825-1:2014, 6.3.

A safety interlock shall be provided for access panels of protective housings of free space beam delivery systems that may include beam shaping and beam switching components when:

- a) the access panel is intended to be removed or displaced during maintenance or operation of the laser processing machine, and
- b) the removal of the panel gives access to laser radiation levels designated by "X" in Table 13 of IEC 60825-1:2014.

The safety interlock shall be part of a design that prevents the removal of the panel until the accessible emission levels are below the AEL defined above. Inadvertent resetting of the interlock shall not in itself restore emission values above the limits specified in 5.3.

If a deliberate override mechanism is provided, the requirements in 6.3.2 of IEC 60825-1:2014 shall apply.

All safety interlocks, safety monitoring devices or associated safety-related control circuits shall meet the requirements specified in ISO 12100 and IEC 61508 (all parts) or ISO 13849-1 with respect to the general requirements for guards together with the requirements related to interlock devices and safety monitoring devices and their application in safety-related control circuits.

G.2.4 Safety interlocks for beam delivery systems using fibre optic cables or other beam waveguides

Removal or displacement of a fibre optic cable (or other form of beam waveguide) in a beam delivery system shall be allowable only under at least one of the following conditions.

- a) With the use of a key or tool at the point of connection to allow access, removal or displacement of the fibre optic cable by skilled or trained persons.
- b) With the prevention of emission from the fibre optic cable by the termination of emission from the laser prior to access to the fibre optical cable end on the removal or displacement of the fibre optic cable. This may be accomplished by the use of interlocks at the interfaces that can be displaced.
- c) Removal or displacement of the fibre optic cable without the use of a key or special tool and without the termination of laser radiation emission from the laser shall be possible only when other protective measures are provided to ensure that personnel are not exposed to laser radiation that will cause injury. These protective measures shall be clearly described in the user instructions together with the necessary procedures for their use.

When a safety interlock is used, removal of the protective housing shall not permit human access to accessible emission levels above the applicable AEL in Table 13 of IEC 60825-1:2014. Inadvertent resetting of the interlock shall not in itself restore emission values above the applicable AEL in Table 13 of IEC 60825-1:2014. These interlocks shall be failsafe or redundant and conform to the requirements in the applicable IEC product standard.

If a deliberate override mechanism is provided, the requirements of 6.3.2 of IEC 60825-1:2014 shall apply.

All safety interlocks, safety monitoring devices or associated safety-related control circuits shall meet the requirements specified in ISO 12100 and IEC 61508 or ISO 13849-1 with respect to the general requirements for guards together with the requirements related to interlock devices and safety monitoring devices and their application in safety-related control circuits.

G.2.5 Environmental conditions

All beam delivery systems shall meet the safety requirements defined in Annex G under all expected operating conditions and foreseeable abuse and misuse appropriate to the intended purpose of the laser processing machine. Factors to be considered shall include:

- a) the intended environment of use;
- b) climatic conditions (temperature, relative humidity, etc.);
- c) anticipated vibration and shock;
- d) electromagnetic interferences.

G.3 Verification of safety requirements or protective measures

General conformance with the requirements of Annex G shall be verified by visual inspection.

Correct functioning of control devices shall be verified in accordance with functional tests specified by the manufacturer.

Verification procedures relating to laser radiation levels shall conform to IEC 60825-1.

Verification of the information for the user shall be confirmed by visual examination of the handbooks and any other relevant information.

G.4 Information for users

G.4.1 Technical documentation

In addition to the requirements of other standards that are used in the manufacture of the laser processing machine, the following information shall be supplied.

- a) Relevant safety-related documentation and details of safe installation and use of the beam delivery system. This shall, where appropriate, include:
 - 1) a clear, comprehensive description of the beam delivery system, its installation and mounting and any connection to the host equipment safety-related controls;
 - 2) electrical supply and other control requirements;
 - 3) laser radiation performance limitations;
 - 4) information on the relevant physical environment.
- b) Relevant safety-related documentation for maintenance and servicing procedures associated with the beam delivery system. This information shall include guidance on the adjustment, maintenance, replacement and repair, particularly of the protective devices and control for use by authorized service personnel.
- c) List of recommended spare parts for use by authorized service personnel.
- d) A description (including interconnection diagrams) of the safeguards, interlocking functions and interlocking of guards. This description shall include situations when removal or displacement of the fibre optic cable without the use of a key or special tool and without the termination of laser radiation emission from the laser shall be possible and when other protective measures are provided to ensure that personnel are not exposed to laser radiation that will cause injury. These protective measures shall be clearly described together with the necessary procedures for their use.

e) A description of the means provided, where it is necessary, to suspend the safeguarding.

G.4.2 Labelling

Access panel warning labels shall be fitted as required and described in Clause 7 of IEC 60825-1:2014.

G.5 Examples of risk assessments

Examples of risk assessments are shown below together in Table G.1 and Table G.2 with potential solutions for risk reduction measures. The list is not comprehensive and alternative technical measures (that may have identical or improved efficiency) for risk reduction can be considered.

Table G.1 – Beam delivery systems using free space beam delivery systems

Use, reasonably foreseeable misuse or abuse	Failure mechanism	Hazard	Example of risk reduction
Beam directed through beam switching device.	Beam switch emits the laser beam partly or wholly guided to an unexpected beam delivery system.	Laser radiation above accessible emission limit (AEL) of Class 1 at unexpected beam delivery system.	Design the beam switching device to avoid this.
Beam directed through beam switching device.	Beam switch not in proper position – laser beam partly or wholly guided to unexpected beam delivery system.	Laser radiation above AEL of Class 1 at unexpected beam delivery system.	Monitor the beam switching device and interlock to ensure the beam switch components are in the correct positions.
Beam being propagated through the free space beam path protective housing.	Mirror or lens damage, breakage or contamination leading to higher degree of scattered radiation that may cause deformation of components in the beam delivering system.	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The beam delivery protective housing to be able to tolerate the foreseeable exposure limit (FEL) (as defined in 3.11) as a passive laser guard, or consider using a correctly designed active guard. Consider apertures to reduce the amount of radiation scattered from a defective mirror, or limit radiation scattered as a result of misalignment. Monitor the local temperature of vulnerable beam delivery components.
Beam being propagated through the free space beam path protective housing.	Mirror breakage leading to excess heating by the laser beam resulting in the deformation of components in the beam delivering system.	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The beam delivery protective housing to be able to tolerate the FEL as passive laser guard, or consider using a correctly designed active guard. Consider apertures to reduce the amount of radiation scattered from a defective mirror, or limit radiation scattered as a result of misalignment. Monitor the local temperature of vulnerable beam delivery components.

Use, reasonably foreseeable misuse or abuse	Failure mechanism	Hazard	Example of risk reduction
Beam being propagated through the free space beam path protective housing.	Mechanical deformations of protective housing. (Damage or deformation due to external forces great enough to temporarily or permanently distort the physical configuration.)	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The beam path protective housing designed to tolerate reasonably foreseeable mechanical forces, or provide an alternative active guard.
Beam being propagated through the free space beam path protective housing.	Displacement of the protective housing due to vibrations etc. that may cause the beam delivery system break-up.	Laser radiation above AEL of Class 1 from openings in beam delivery system.	The use of well-tried proven design methods that tolerate foreseeable operating stresses and widely used with successful results in similar applications. Conduct regular inspection.
Beam being propagated through the free space beam path protective housing.	Misalignment of mirrors.	The beam exposing the protective housing to levels higher than its protective exposure limit (PEL) (as defined in 3.21).	The use of well-tried proven design methods that tolerate foreseeable operating stresses and are widely used with successful results in similar applications. Prevent misaligned beam from propagating further in the beam delivery system. Incorporate apertures and baffles/barriers to restrict propagation. Restrict the number and extent of adjustments.
Beam being propagated through the free space beam path protective housing.	Unclear identification of beam delivery components resulting in incorrect parts being installed and subsequent damage of both the parts themselves and other parts of the machine or workpiece.	Laser radiation above AEL of Class 1 from openings in beam delivery system. Damage to associated parts of the machine.	Ensure that all beam delivery system components and parts are labelled to allow easy identification. Provide adequate instructions to minimize the risk of using incorrect parts or of incorrect assembly or adjustment. Incorporate interlocks to prevent incorrect parts or assembly.
Incorrect mounting of beam shaping optics.	Human error.	Laser radiation above AEL of Class 1 (by escaping the protected laser area, or exceeding the laser guard PEL).	Provide adequate instructions to minimize the risk of using incorrect parts or of incorrect assembly or adjustment. Conduct regular inspections.

Use, reasonably foreseeable misuse or abuse	Failure mechanism	Hazard	Example of risk reduction
Damage of beam shaping optics.	From collision with workpiece, overheated optics due to contamination or cooling water failure.	Laser radiation above AEL of Class 1 (by escaping the protected laser area, or exceeding the laser guard PEL).	Ensure that all beam delivery system components and parts are labelled to allow easy identification. Provide adequate instructions to minimize the risk of using incorrect parts or of incorrect assembly or adjustment. Incorporate interlocks or mechanical location keys to prevent the use of incorrect parts or incorrect assembly. Monitor the local temperature of vulnerable beam delivery components.

Table G.2 – Beam delivery systems using fibre optic cables

Use, reasonably foreseeable misuse or abuse	Possible failure mechanism	Hazard	Examples of risk reduction
Beam directed through beam switching device.	Beam switch "leaks" – laser beam partly or wholly guided to unexpected beam delivery system.	Laser radiation above AEL of Class 1 at unexpected beam delivery system.	Design the beam switching device to avoid this.
Beam directed through beam switching device.	Beam switch not in the correct position – laser beam partly or wholly guided to unexpected beam delivery system.	Laser radiation above AEL of Class 1 at the unexpected beam delivery system.	Monitor the beam switching device and interlock to ensure the beam switch components are in the correct positions.
Beam being coupled into fibre.	Damage (i.e. thermal) to coupling optics.	The coupling optical components or assemblies overheat to a degree where it damages or deforms, resulting in either leaking radiation or the production of errant beams.	The coupling optical components or assemblies to be designed to handle power passively. Interlock of the beam. Monitor component temperature and interlock into the control system.
Beam being coupled into fibre.	Damaged fibre at the input surface.	Fibre connector heats up to a degree where it deforms and laser radiation is not correctly coupled into the fibre.	Fibre connector designed to handle power passively. Introduce beam monitoring schemes and interlock into the control system.
Beam reflected from a work piece or target being coupled back into fibre.	Damaged fibre at the output surface and subsequent burn back or fusing of the fibre.	Fibre output connector heats up to a degree where it deforms and the fibre optic cable may be damaged.	Fibre connector designed to handle power passively. Introduce beam monitoring schemes and interlocks into the control system.

Use, reasonably foreseeable misuse or abuse	Possible failure mechanism	Hazard	Examples of risk reduction
Beam in fibre optic cable.	Breakage due to mechanical forces on the fibre.	Laser radiation above AEL of Class 1 emitted from a broken fibre to the surrounding environment. Possible fire hazard.	Fibre to be put inside protective cover that protects from mechanical forces in the operating environment and potential misuse/abuse. Use the protective housing to limit excessive twist. Provide strain relief at the optical fibre terminations to minimize bending and twisting. Make the protective housing an active guard linked into the control system. Monitor component temperature and interlock into the control system.
With the laser beam being directed through the fibre optic, the fibre is subjected to repetitive flexing.	Breakage due to fatigue.	Laser radiation above AEL of Class 1 emitted from a broken fibre to the surrounding environment.	Design the protective housing to restrict the bending radius to prevent fibre breakage. Provide strain relief at the optical fibre terminations to minimize bending and twisting. Design a reinforced protective housing to be able to tolerate the laser radiation of the inner surface at the protective housing. Make the protective housing an active guard linked into the control system
With the laser beam being directed through the fibre optic, the fibre is subjected to repetitive flexing.	Breakage due to other than mechanical forces (optical degrading, first pulses, etc.).	Laser radiation above AEL of Class 1 from a broken fibre to the surrounding environment.	The protective housing to be able to retain the laser radiation of the inner surface of the protective housing without breakthrough. Make the protective housing an active guard linked into the control system.
Unconnected fibre at the output of the fibre optic cable emitting laser radiation from the laser. Unconnected fibre at the input of the fibre optic cable emitting laser radiation from the laser.	Human error. Mechanical loosening of fixings due to incorrect assembly or vibrations, for example.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Interlock the fibre interface/connector. Ensure that the fixings and associated tools used to mount/dismount fibre interface are adequate. Minimize the requirement for the interface to be interfered with. Restrict this activity to service work carried out by skilled and authorized personnel with special training. Design a reinforced laser guard.

Use, reasonably foreseeable misuse or abuse	Possible failure mechanism	Hazard	Examples of risk reduction
Incorrect mounting of beam shaping optics.	Human error.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Ensure design is adequately robust. Ensure instructions are sufficient for adjustments to be made securely. Recommend inspection intervals.
Damage of beam shaping optics.	From collision with workpiece, overheated optics due to contamination or cooling water failure.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Design considerations to include the complete laser guard. Provide collision protection or interlocks.
Multiple fibres – mix of fibres.	Human error.	Laser radiation being emitted in an undefined and uncontrolled direction leading to potential exposure above AEL of Class 1 (by escaping the laser guarded area, or exceeding any other laser guard PEL).	Orientate, mechanically interlock or clearly and indelibly mark fibre optic cables. Ensure instructions are clear and unambiguous. If the fibre optic cables transmit the laser beam to separate laser guarded enclosures, interlock the enclosure together with the fibre optic cable.

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ISO/TR 7250-2, *Basic human body measurements for technological design – Part 2: Statistical summaries of body measurements from national populations*

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ISO 14120, *Safety of machinery – Guards – General requirements for the design and construction of fixed and movable guards*

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

SÉCURITÉ DES APPAREILS À LASER –

Partie 4: Protecteurs pour laser

AVANT-PROPOS

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Cette troisième édition annule et remplace la deuxième édition parue en 2006, l'Amendement 1:2008 et l'Amendement 2:2011. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- a) Des modifications significatives ont été apportées et la présente édition a été établie pour le confort de l'utilisateur.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
76/704/FDIS	76/711/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Le présent document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/standardsdev/publications.

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INTRODUCTION

À de faibles niveaux d'éclairement ou d'exposition énergétique, la sélection du matériau et de l'épaisseur de la protection contre le rayonnement laser est déterminée essentiellement par le besoin de fournir une atténuation optique suffisante. Cependant, à des niveaux plus élevés, une considération supplémentaire est la capacité du rayonnement laser à enlever le matériau du protecteur – généralement par fusion, oxydation ou ablation, procédés qui peuvent conduire à un rayonnement laser pénétrant un matériau normalement opaque.

L'IEC 60825-1 traite de questions fondamentales concernant les protecteurs pour laser, y compris l'accès humain, les dispositifs d'interverrouillage et l'étiquetage, et fournit des recommandations générales relatives à la conception de capots et d'enceintes de protection pour les lasers de forte puissance.

Les protecteurs pour laser peuvent également être conformes aux normes pour les protecteurs oculaires contre le rayonnement laser, mais une telle conformité n'est pas nécessairement suffisante pour satisfaire aux exigences du présent document.

Lorsque le terme "éclairement énergétique" est utilisé, l'expression implique "éclairement ou exposition énergétique, selon le cas".

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SÉCURITÉ DES APPAREILS À LASER –

Partie 4: Protectors pour laser

1 Domaine d'application

La présente partie de l'IEC 60825 spécifie les exigences relatives aux protecteurs pour laser, permanents et temporaires (par exemple, pour l'entretien), qui protègent la zone de traitement d'une machine à laser, ainsi que les spécifications pour les protecteurs d'origine pour laser.

Le présent document s'applique à tous les composants d'un protecteur, y compris les écrans clairs (visiblement transmetteurs) et les fenêtres d'observation, les panneaux, les rideaux pour laser et les parois.

De plus, le présent document indique

- a) comment évaluer et spécifier les propriétés de protection d'un protecteur pour laser, et
- b) comment sélectionner un protecteur pour laser.

NOTE Les exigences pour les composants du trajet du faisceau, les dispositifs d'arrêt du faisceau et les autres parties d'un capot de protection d'un appareil à laser qui ne protègent pas la zone de traitement sont contenues dans l'IEC 60825-1.

Le présent document traite de la protection contre le rayonnement laser uniquement. Les dangers en provenance du rayonnement secondaire qui peuvent se produire au cours du traitement des matériaux ne sont pas étudiés.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60825-1:2014, *Sécurité des appareils à laser – Partie 1: Classification des matériels et exigences*

IEC 61508 (toutes les parties), *Sécurité fonctionnelle des systèmes électriques/électroniques/électroniques programmables relatifs à la sécurité*

ISO 11553-1, *Sécurité des machines – Machines à laser – Partie 1: Exigences de sécurité laser*

ISO 12100, *Sécurité des machines – Principes généraux de conception – Appréciation du risque et réduction du risque*

ISO 13849-1, *Sécurité des machines – Parties des systèmes de commande relatives à la sécurité – Partie 1: Principes généraux de conception*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC 60825 ainsi que les suivants, s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse <http://www.electropedia.org/>
- ISO Online browsing platform: disponible à l'adresse <http://www.iso.org/obp>

3.1

panneau d'accès

panneau qui, lorsqu'il est retiré ou déplacé, fournit un accès humain au rayonnement laser

Note 1 à l'article: Le gainage autour d'une fibre, les tubes utilisés comme composants de l'enveloppe ou tout dispositif qui sert de panneau amovible ou déplaçable, peuvent également être désignés comme "panneau d'accès" selon les termes de cette définition.

3.2

temps de protection du protecteur actif

temps minimal pour une exposition donnée à des rayonnements laser de la surface frontale (incidente) d'un protecteur actif pour laser, mesuré à partir de l'émission d'un signal d'interruption du protecteur actif, pendant lequel le protecteur actif pour laser peut empêcher de façon sûre au niveau de sa surface arrière le rayonnement laser accessible de dépasser la LEA (limite d'émission accessible) de la classe 1

3.3

signal d'interruption du protecteur actif

signal émis par un protecteur actif en réponse à une exposition excessive de sa surface frontale au rayonnement laser, et qui est destiné à entraîner une interruption automatique du rayonnement laser

Note 1 à l'article: L'action d'un interverrouillage de sécurité qui crée un circuit ouvert est considérée comme un "signal" dans ce contexte.

3.4

protecteur actif pour laser

protecteur pour laser qui fait partie d'un système de commande lié à la sécurité dans lequel toute défaillance de la surface frontale du protecteur pour laser déclenche un signal d'interruption

3.5

système de transmission du faisceau

système qui comprend tous les composants, y compris tous les composants du faisceau optique et les trajets du faisceau potentiels et leurs enveloppes, qui lorsqu'ils sont combinés, transfèrent le rayonnement laser émis par le générateur de rayonnement laser (le laser) vers la pièce à traiter

Note 1 à l'article: Ces composants peuvent comprendre tous les éléments pour le guidage, la conformation et la commutation du faisceau laser ainsi que l'enveloppe et le support pour les composants du trajet du faisceau. Voir l'Annexe G pour des informations détaillées sur les systèmes de transmission du faisceau guidé.

3.6

diamètre du faisceau

d_{86}

plus petit diamètre d'une ouverture circulaire dans un plan perpendiculaire à l'axe du faisceau qui contient 86 % de la puissance (ou énergie) totale du laser

Note 1 à l'article: Dans le cas d'un faisceau gaussien (TEM_{00}), d_{86} est le point auquel l'éclairement énergétique (exposition énergétique) baisse à $1/e^2$ de sa valeur de crête centrale et des moments au second ordre de la distribution de densité de puissance (ISO 11146-1:2005, 3.2).

3.7

composant du trajet du faisceau

composant optique qui contribue à définir le trajet de faisceau

Note 1 à l'article: Des exemples de composant de trajet du faisceau comprennent un miroir d'orientation du faisceau, une lentille de focalisation ou un connecteur à fibre optique.

[SOURCE: IEC 60825-1:2014, 3.16, modifiée— Exemple supprimé et Note 1 à l'article ajoutée]

3.8

composant de conformation du faisceau

composant optique introduit dans le trajet du faisceau pour transformer le profil ou la section droite du faisceau laser au moyen d'ouvertures ou de composants optiques réfléchissants, réfringents ou diffractifs

3.9

composant de commutation du faisceau

composant optique ou ensemble de composants introduits dans le trajet du faisceau pour diriger ou détourner, d'après une commande extérieure, le trajet du faisceau selon des direction(s) prédéterminée(s), la commande extérieure permettant au trajet du faisceau d'être commuté d'une direction prédéterminée à un autre

3.10

câble de fibre optique

composant de guidage du faisceau optique qui permet la transmission du rayonnement laser le long d'un support transparent

Note 1 à l'article: Un câble de fibre optique peut avoir un cœur en verre ou tout autre cœur qui transporte le rayonnement laser et peut être entouré d'une gaine. L'extérieur de la fibre est protégé par une gaine et peut être, en plus, protégé par des couches supplémentaires d'un autre matériau, tel qu'un polymère ou un métal en vue de protéger la fibre contre les déformations mécaniques, la pénétration d'eau, etc. Ce terme inclut d'autres formes de dispositifs de transmission, telles que des guides d'ondes.

3.11

limite prévisible d'exposition

LPE

exposition maximale à des rayonnements laser de la surface frontale du protecteur pour laser, dans l'espacement des contrôles d'entretien, évaluée dans des conditions normales et dans des conditions de défaut raisonnablement prévisible

Note 1 à l'article: La spécification complète d'une LPE comprend divers éléments dont l'éclairement énergétique et la durée d'exposition. De plus amples informations sont données à l'Annexe B.

3.12

surface frontale

face du protecteur pour laser prévue pour être exposée aux rayonnements lasers

3.13

protecteur pour laser

écran physique qui limite l'étendue d'une zone de risque en empêchant le rayonnement laser accessible au niveau de sa surface arrière de dépasser la LEA de la classe 1

3.14

machine à laser

machine qui utilise un laser pour traiter les matériaux et qui relève du domaine d'application de l'ISO 11553-1

3.15

temps d'interruption du laser

temps maximal pris, à partir de la production d'un signal d'interruption du protecteur actif, pour que le rayonnement laser soit interrompu

Note 1 à l'article: Le temps d'interruption du laser ne se rapporte pas à la réponse d'un protecteur actif pour laser, mais à la réponse de la machine à laser, en particulier de l'obturateur de sécurité du laser.

3.16

espacement des contrôles d'entretien

temps qui s'écoule entre les contrôles d'entretien de sécurité successifs d'un protecteur pour laser

3.17

temps de protection du protecteur passif

temps minimal déterminé pour une exposition à des rayonnements laser égale à une limite d'exposition protégée (LEP) donnée de la surface frontale (incidente) d'un protecteur passif pour laser, pendant lequel le protecteur passif pour laser peut empêcher de façon sûre au niveau de sa surface arrière le rayonnement laser accessible de dépasser la LEA de la classe 1

3.18

protecteur passif pour laser

protecteur pour laser qui ne repose pour son fonctionnement que sur ses propriétés physiques

3.19

zone de traitement

zone dans laquelle le faisceau laser interagit avec le matériau à traiter

3.20

protecteur d'origine pour laser

protecteur passif ou actif pour laser, proposé par un fabricant de protecteurs pour laser au marché comme un produit indépendant avec une limite d'exposition protégée spécifiée

3.21

limite d'exposition protégée

LEP

exposition maximale à des rayonnements lasers de la surface frontale d'un protecteur pour laser qui empêche le rayonnement laser accessible au niveau de sa surface arrière de dépasser la LEA de la classe 1 pour le temps de détection du protecteur passif ou actif déterminé

Note 1 à l'article: En pratique, il peut y avoir plusieurs expositions maximales à des rayonnements lasers.

Note 2 à l'article: Différentes LEP peuvent être attribuées à différents emplacements d'un protecteur pour laser, si ces emplacements sont clairement identifiables (par exemple, une fenêtre d'observation qui fait partie intégrante d'un protecteur pour laser).

Note 3 à l'article: Voir 5.3 pour les exigences de performance et voir 5.4 pour la spécification complète. La spécification complète d'une LEP comprend divers éléments dont l'éclairement énergétique et la durée d'exposition.

3.22

surface arrière

surface d'un protecteur pour laser qui est éloignée du rayonnement laser associé et généralement accessible à l'utilisateur

3.23

raisonnablement prévisible

<événement ou condition> crédible et dont la probabilité d'apparition (ou d'existence) ne peut pas être négligée

3.24

contrôle d'entretien de sécurité

contrôle documenté réalisé conformément aux instructions du fabricant

3.25

protecteur temporaire pour laser

protecteur de substitution pour laser ou protecteur supplémentaire actif ou passif, destiné à limiter l'étendue de la zone de risque au cours de certaines opérations d'entretien de la machine à laser

4 Exigences relatives aux protecteurs pour laser

4.1 Exigences

L'Article 4 spécifie les exigences applicables aux protecteurs pour laser qui protègent la zone de traitement et sont fournis par le fabricant de la machine à laser.

4.2 Exigences de conception

4.2.1 Exigence relative au protecteur

Un protecteur pour laser doit satisfaire à l'ISO 12100 en ce qui concerne les exigences générales pour les protecteurs et également les exigences plus spécifiques concernant leur emplacement et leur méthode de fixation. De plus, les exigences spécifiques suivantes concernant les lasers doivent être satisfaites par un protecteur pour laser.

4.2.2 Exigences générales

Un protecteur pour laser, à son emplacement prévu, ne doit donner lieu à aucun danger associé au niveau ou au-delà de sa surface arrière lorsqu'il est exposé à un rayonnement laser primaire ou un rayonnement optique secondaire jusqu'à la limite d'exposition prévisible. L'Annexe F fournit des recommandations pour l'évaluation de l'aptitude des protecteurs pour laser.

NOTE 1 Parmi les dangers associés figurent les températures élevées, le plasma, le rayonnement ultraviolet excessif, le dégagement de matières toxiques, les incendies, les explosions et l'électricité.

NOTE 2 Voir l'Annexe B pour l'évaluation de la limite d'exposition prévisible.

4.2.3 Consommables des protecteurs pour laser

Des dispositions doivent être prises pour le remplacement des parties d'un protecteur pour laser susceptibles d'être endommagées par le rayonnement laser.

NOTE Un écran sacrificiel ou interchangeable constitue un exemple d'une telle partie.

4.3 Exigences de performance

4.3.1 Généralités

Lorsque la surface frontale (incidente) d'un protecteur pour laser est exposée à un rayonnement laser à la limite d'exposition prévisible, le protecteur pour laser doit empêcher le rayonnement laser accessible au niveau de sa surface arrière de dépasser la LEA de la classe 1 à tout moment dans l'espace des contrôles d'entretien. Pour les machines à laser automatiques destinées aux fonctionnements sans surveillance et/ou encadrement, la valeur minimale de l'espace des contrôles d'entretien doit être de 8 h.

Cette exigence doit être satisfaite pendant la durée de vie prévue du protecteur pour laser dans les conditions envisagées de fonctionnement.

NOTE 1 Cette exigence implique à la fois une faible transmission du rayonnement laser et la résistance aux dommages qui résultent du rayonnement laser.

NOTE 2 Certains matériaux peuvent perdre leurs propriétés de protection en raison du vieillissement, de l'exposition aux rayonnements ultraviolets, de certains gaz, de la température, de l'humidité et d'autres conditions d'environnement. De plus, certains matériaux transmettent un rayonnement laser sous une exposition à des

rayonnements laser de forte intensité, même lorsqu'il n'y a aucun dommage visible (c'est-à-dire, blanchissement réversible).

4.3.2 Protecteurs actifs pour laser

- a) Le temps de protection du protecteur actif doit dépasser le temps d'interruption du laser jusqu'aux limites d'exposition prévisibles.
- b) Si un protecteur actif détecte une exposition excessive, à savoir déclenché, il doit émettre un avertissement visible ou sonore. Un réarmement manuel est exigé avant que l'émission laser puisse recommencer.

NOTE Voir l'Annexe C qui développe ces notions.

4.4 Validation

4.4.1 Validation générale du protecteur

Si le fabricant de machines à laser choisit de faire un protecteur pour laser, le fabricant doit confirmer que le protecteur est conforme aux exigences de conception et peut satisfaire aux exigences de performance établies en 4.3.

NOTE Voir l'Annexe A qui donne des recommandations relatives à la conception et à la sélection des protecteurs pour laser.

4.4.2 Validation des performances

4.4.2.1 Le protecteur pour laser complet ou un échantillon approprié du matériau de construction du protecteur pour laser doit être soumis aux essais à chaque LPE identifiée.

Il est prévu qu'un tableau des LPE prédéterminées pour les combinaisons communes de lasers et de matériaux de protection, fasse, conjointement avec des procédures d'essai appropriées, fassent l'objet d'une annexe informative dans un amendement ultérieur au présent document. Cela peut fournir une alternative simple aux essais directs dans la plupart des cas.

NOTE Voir l'Annexe B pour l'évaluation de la LPE et voir l'Annexe C pour une élaboration plus approfondie des termes LEP et LPE.

4.4.2.2 En vue de la réalisation d'essais, l'exposition à la LPE doit être atteinte soit:

- a) en calculant ou en mesurant l'exposition et en reproduisant les conditions; soit
- b) sans quantifier la LPE, en créant les conditions de la machine dans lesquelles la LPE est produite.

L'état du protecteur pour laser ou de l'échantillon doit être représentatif des conditions physiques de la surface frontale permises dans le cadre des instructions de contrôles périodiques et pour la durée utile du protecteur, qui réduisent le plus possible les propriétés de protection contre le rayonnement laser du protecteur pour laser (par exemple, usure et contamination de surface) (voir 4.5.2).

4.5 Guide de l'utilisateur

4.5.1 Le fabricant doit fournir à l'utilisateur la documentation qui indique l'espacement des contrôles d'entretien pour le protecteur pour laser, fournir toutes les précisions relatives au contrôle et à ses procédures d'essai, au nettoyage, au remplacement ou à la réparation des pièces endommagées, accompagnés de toutes les restrictions d'utilisation.

4.5.2 Le fabricant doit fournir à l'utilisateur la documentation qui indique qu'après toute activation du système de commande de sécurité d'un protecteur actif, la cause doit être recherchée et la recherche des dommages doit être effectuée. Les instructions doivent également inclure les mesures correctives nécessaires à entreprendre avant de réinitialiser le système de commande.

5 Protecteur d'origine pour laser

5.1 Généralités

L'Article 5 spécifie les exigences à satisfaire par les fournisseurs de protecteur d'origine pour laser.

5.2 Exigences de conception

Un protecteur d'origine pour laser ne doit pas créer de dangers associés au niveau ou au-delà de sa surface arrière lorsqu'il est exposé à un rayonnement laser jusqu'à la LEP spécifiée, lorsqu'il est utilisé comme cela est spécifié dans le guide de l'utilisateur (voir 5.7).

5.3 Exigences de performance

Le rayonnement laser accessible au niveau de la surface arrière du protecteur pour laser ne doit pas dépasser la LEA de la classe 1 lorsque sa surface frontale est soumise au rayonnement laser à la LEP spécifiée, au moins pendant le temps de protection du protecteur passif. Pour un protecteur actif pour laser, cette exigence doit s'appliquer pour le rayonnement laser accessible pendant la période du temps de protection du protecteur actif, mesurée à partir du moment de l'émission d'un signal d'interruption du protecteur actif.

Cette exigence doit être satisfaite pendant la durée de vie prévue du protecteur dans les conditions prévues d'entretien.

5.4 Exigences de spécification

La spécification complète d'une LEP doit inclure les informations suivantes:

- a) l'amplitude de l'éclairement ou de l'exposition énergétique au niveau de la surface frontale du protecteur pour laser (en unités de $W m^{-2}$ ou $J m^{-2}$, respectivement) utilisée pour mesurer son temps de protection du protecteur passif et la valeur moyenne ainsi que l'écart-type de sa limite de temps d'exposition soumise à l'essai pour le calcul de son temps de protection du protecteur passif, spécifiant toute limite supérieure concernant la zone d'exposition;
- b) le temps de protection du protecteur passif cité qui comprend le facteur de sécurité de 0,7 (voir l'Article D.3 pour le calcul du temps de protection cité pour les protecteurs passifs pour laser);
- c) les longueurs d'onde pour lesquelles cette LEP s'applique;
- d) l'angle d'incidence et (le cas échéant) la polarisation du rayonnement laser incident;
- e) toutes les dimensions minimales concernant la zone exposée (par exemple, comme cela peut s'appliquer à un protecteur actif pour laser avec des capteurs discrets, de sorte qu'un faisceau laser de petit diamètre puisse traverser le protecteur sans être détecté);
- e) pour un protecteur actif pour laser, le temps de protection du protecteur actif.

NOTE 1 Voir l'Article B.1 qui développe ces notions.

NOTE 2 Dans tous les cas, une plage ou un ensemble de valeurs peut être établi(e) plutôt qu'une valeur unique.

NOTE 3 Une représentation graphique est admise (par exemple, éclairement énergétique par rapport à la durée, tous les autres paramètres étant constants).

5.5 Exigences d'essai

5.5.1 Généralités

Les essais doivent être réalisés à l'aide du protecteur pour laser complet ou d'un échantillon approprié du matériau utilisé pour construire le protecteur. Dans les deux cas, l'état du protecteur ou de l'échantillon doit être tel qu'il reproduise ou dépasse la condition physique admissible la plus défavorable de la surface frontale, y compris de réflexion de surface réduite et des dommages autorisés dans le cadre des instructions d'entretien périodique (voir 5.7).

Le rayonnement sur la surface frontale doit être soit comme cela est spécifié par la LEP, soit, dans le cas des essais sur échantillon, comme cela est spécifié en 5.5.2.

Lorsque la surface frontale est soumise aux conditions d'exposition à la LEP, le rayonnement laser accessible mesuré au niveau de la surface arrière du protecteur pour laser ne doit pas dépasser la LEA de la classe 1 (essais tels qu'ils sont spécifiés à l'Article 5 de l'IEC 60825-1:2014). Cette exigence s'applique pendant la durée d'exposition spécifiée dans la LEP ou, dans le cas d'un protecteur actif, pendant le temps de protection spécifié du protecteur actif mesuré à partir du moment de l'émission d'un signal d'interruption du protecteur actif.

NOTE Dans les cas où des matériaux opaques à la ou aux longueurs d'ondes du laser sont utilisés (par exemple, les métaux), le rayonnement transmis ne peut atteindre la LEA de la classe 1 qu'après le retrait physique complet (ou presque complet) du matériau le long du cheminement du rayonnement jusqu'à la surface arrière. Dans de tels cas, l'évolution d'un état sans transmission à un état de transmission qui dépasse largement la LEA de la classe 1 est par conséquent rapide, et des détecteurs de rayonnement sensibles ne sont pas exigés.

5.5.2 Essais sur échantillon

Les essais de l'échantillon de protecteur doivent être réalisés en irradiant la surface frontale du matériau du protecteur selon la procédure et la méthodologie spécifiées dans l'Annexe D.

5.6 Exigences d'étiquetage

5.6.1 Tout étiquetage doit être situé sur la surface arrière du protecteur.

5.6.2 La surface arrière du protecteur doit être clairement identifiée si l'orientation du protecteur a de l'importance.

5.6.3 Si une partie seulement de la surface frontale de la protection est un protecteur pour laser, cette zone doit être clairement identifiée par un surlignage coloré en gras et par des mots pour indiquer la limite extérieure du protecteur pour laser.

5.6.4 L'étiquetage doit indiquer la spécification complète de la LEP.

5.6.5 Le nom du fabricant, la date et le lieu de la fabrication conformément à l'ISO 11553-1, et une déclaration de conformité au présent document doivent être fournis.

5.7 Guide de l'utilisateur

En plus des spécifications répertoriées en 5.4, les informations suivantes doivent être fournies à l'utilisateur par le fabricant d'un protecteur d'origine pour laser:

- une description des utilisations autorisées du protecteur pour laser;
- une description du montage et du raccordement du protecteur pour laser;
- des informations sur l'installation du protecteur pour laser – pour les protecteurs actifs pour laser, cela doit inclure les exigences d'interface et d'alimentation du protecteur;
- des exigences d'entretien, y compris par exemple les informations détaillées au contrôle et aux procédures d'essai, de nettoyage, de remplacement ou de réparation des pièces endommagées;

- e) des instructions qui spécifient qu'après toute activation du système de commande de sécurité d'un protecteur actif, la cause doit être recherchée et la recherche des dommages doit être effectuée. Les instructions doivent également inclure les mesures correctives nécessaires à entreprendre avant de réinitialiser le système de commande;
- f) l'étiquetage indiqué en 5.6 et son emplacement. Si seule une partie de la surface frontale du protecteur constitue un protecteur pour laser, cette zone doit être identifiée;
- g) une déclaration de conformité au présent document.

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Annexe A (informative)

Recommandations générales sur la conception et la sélection des protecteurs pour laser

A.1 Conception des protecteurs pour laser

A.1.1 Protecteurs passifs pour laser

Des protecteurs passifs pour laser peuvent prendre la forme, par exemple:

- a) d'un panneau métallique reposant sur la conduction thermique, au besoin amélioré par de l'air pulsé ou par un refroidissement par eau afin de maintenir la température de la surface en dessous de son point de fusion dans des conditions normales et dans des conditions de défaut raisonnablement prévisible;
- b) d'une feuille transparente, opaque à la longueur d'onde du laser, qui n'est pas affectée par de faibles valeurs d'exposition à des rayonnements laser en fonctionnement normal de la machine à laser;
- c) de panneaux non métalliques qui reposent sur la sublimation thermique sans fusion et matériaux similaires.

A.1.2 Protecteurs actifs pour laser

Des protecteurs actifs pour laser peuvent prendre la forme, par exemple:

- a) d'un protecteur, avec des capteurs thermiques discrets et incorporés, qui détectent les échauffements;
Il convient de prendre en considération l'espacement entre les capteurs par rapport aux dimensions minimales d'un faisceau laser erratique.
- b) d'un protecteur pour laser qui comprend deux panneaux entre lesquels est contenu un liquide sous pression ou un milieu gazeux combiné à un dispositif détecteur de pression capable de détecter la chute de pression due à la perforation de la surface frontale.

A.1.3 Indication des dangers (protecteurs passifs pour laser)

Il convient, dans la mesure du possible, de fournir une indication visible de l'exposition du protecteur pour laser à des quantités dangereuses de rayonnement laser (par exemple, en ajoutant une couche d'une peinture appropriée sur les deux côtés du protecteur pour laser).

A.1.4 Alimentation (protecteurs actifs pour laser)

Si le fonctionnement correct d'un protecteur actif repose sur la présence d'alimentation, il convient de concevoir le circuit d'alimentation de sorte que le fonctionnement du laser ne soit pas possible en l'absence d'alimentation.

A.2 Sélection des protecteurs pour laser

A.2.1 Exigences de sélection

Un processus de sélection simple se déroule de la façon suivante.

- a) Identifier la position préférentielle du protecteur pour laser et estimer la LPE à cet emplacement. L'Annexe B donne des recommandations relatives à l'estimation des valeurs de la LPE.

- b) Au besoin, réduire le plus possible la LPE dans des conditions de défaut, de préférence en incluant un contrôle automatique dans la machine afin de détecter les conditions de défaut et de limiter la durée d'exposition. Des exemples d'alternatives comprennent les éléments suivants:
- 1) s'assurer que le protecteur pour laser est suffisamment éloigné du point focal produit par l'optique de focalisation;
 - 2) installer les parties vulnérables du protecteur pour laser (telles que les fenêtres d'observation) loin des régions qui peuvent être exposées à un éclairage énergétique élevé;
 - 3) éloigner le protecteur pour laser de la zone de traitement au laser;
 - 4) exiger dans la documentation essentielle sur l'entretien pour les protecteurs temporaires pour laser, des ajouts tels que:
 - une ou plusieurs personnes doivent être présentes et surveiller l'état de la surface frontale du protecteur pour laser, afin de réduire la durée d'exposition évaluée d'un protecteur passif pour laser;
 - un contrôleur à action maintenue doit être utilisé par la ou les personnes surveillant l'état de la surface frontale du protecteur pour laser, afin de réduire la durée d'exposition évaluée d'un protecteur passif pour laser;
 - un protecteur temporaire local supplémentaire, des diaphragmes et des dispositifs d'absorption de faisceau doivent être utilisés, afin d'absorber tous les faisceaux laser erratiques puissants;
 - la zone de risque doit être limitée par des dispositifs d'avertissement de faisceaux erratiques et le protecteur placé au-delà de cette zone afin de réduire la durée d'exposition évaluée;
 - 5) incorporer dans la conception de la machine, lors de l'utilisation de protecteurs temporaires pour laser, des éléments de contrôle du faisceau afin de faciliter un contrôle amélioré du faisceau laser au cours des opérations d'entretien, tels que:
 - des supports pour l'emplacement précis de composants supplémentaires qui forment le faisceau (par exemple, miroirs de déflexion) exigés au cours de l'entretien;
 - des montages qui permettent uniquement une étendue limitée pour l'orientation du faisceau.

Trois options se présentent ensuite. L'ordre ci-dessous n'indique pas une préférence.

A.2.2 Option 1: protecteur passif pour laser

Il s'agit de l'option la plus simple.

Les contrôles de conception et de qualité revêtent une importance particulière lorsque l'absorption au niveau de la longueur d'onde du laser est dominée par un additif minoritaire tel qu'un colorant dans un plastique. Dans de tels cas, lorsque le fabricant du matériau ne spécifie pas la concentration de l'absorbeur ou l'atténuation optique du matériau au niveau de la longueur d'onde du laser, il convient de soumettre dans un premier temps aux essais des échantillons en provenance du même lot de matériau, comme cela est décrit en 4.4.1.

A.2.3 Option 2: protecteur actif pour laser

Si la LPE ne peut être réduite à une valeur à laquelle des matériaux de protection courants assurent une protection adéquate sous la forme d'un protecteur passif pour laser, un protecteur actif pour laser peut toujours être utilisé.

A.2.4 Option 3: protecteur d'origine pour laser

Un protecteur d'origine pour laser peut être utilisé si les valeurs évaluées de la LPE sont inférieures aux valeurs de la LEP citées par le fabricant du protecteur pour laser.

Annexe B (informative)

Évaluation de la limite prévisible d'exposition (LPE)

B.1 Généralités

Les valeurs de la LPE peuvent être évaluées soit par mesurage, soit par calcul (voir ci-dessous).

L'ISO 12100 fournit une méthodologie générale pour l'appréciation du risque. Il convient que l'appréciation prenne en considération l'exposition cumulée en fonctionnement normal (par exemple, au cours du cycle de traitement de chaque pièce de la machine) pour l'espacement des contrôles d'entretien.

À partir de cette appréciation, il convient d'identifier les combinaisons les plus exigeantes de rayonnement, la zone d'exposition et la durée d'exposition; voir la Figure B.1, la Figure B.2 et la Figure B.3. Il est assez probable que plusieurs LPE soient identifiées; par exemple, une condition peut augmenter le plus possible la durée d'exposition à un éclairage énergétique relativement faible, tandis qu'une autre condition peut augmenter le plus possible l'éclairage énergétique au cours d'une durée d'exposition plus courte; voir la Figure B.3 et la Figure B.4.

La spécification complète d'une LPE comprend les informations suivantes.

- a) L'éclairage énergétique maximal au niveau de la surface frontale du protecteur pour laser, voir la Figure B.1 et la Figure B.2.

NOTE 1 L'éclairage énergétique est exprimé comme la puissance ou l'énergie totale divisée par la zone de la surface frontale du protecteur, ou la zone limitée spécifiée, selon le cas.

- b) Toute limite supérieure concernant la zone d'exposition de la surface frontale à ce niveau d'éclairage énergétique.

NOTE 2 Aucune limite concernant la zone n'est appropriée pour la protection contre le rayonnement laser diffusé, tandis qu'une limite supérieure concernant la zone exposée est appropriée pour l'exposition directe aux faisceaux laser.

- c) Les caractéristiques temporelles de l'exposition, c'est-à-dire onde entretenue (CW - continuous wave) ou rayonnement laser pulsé et, dans ce dernier cas, la durée d'impulsion et la fréquence de répétition des impulsions.

- d) La durée totale d'exposition.

NOTE 3 Voir l'Article B.4 qui développe cette notion.

- e) La ou les longueurs d'onde du rayonnement laser.

- f) L'angle d'incidence et (le cas échéant) la polarisation du rayonnement, voir la Figure B.1 et la Figure B.2.

NOTE 4 La stipulation de l'angle d'incidence est particulièrement importante pour les protecteurs pour laser exploitant des couches interférentielles pour refléter le rayonnement laser incident.

ATTENTION: Au niveau de l'angle d'incidence "p" de Brewster, le rayonnement polarisé est fortement couplé dans la surface du protecteur.

- g) Toutes les dimensions minimales concernant la zone exposée (par exemple, comme cela peut s'appliquer à un protecteur actif pour laser avec des capteurs discrets, de sorte qu'un faisceau laser de petit diamètre puisse traverser le protecteur pour laser sans être détecté).
- h) Pour un protecteur actif pour laser, le temps de protection du protecteur actif.

B.2 Réflexion du rayonnement laser

B.2.1 Réflexions diffuses

Soit un réflecteur lambertien avec une réflectivité de 100 %,

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

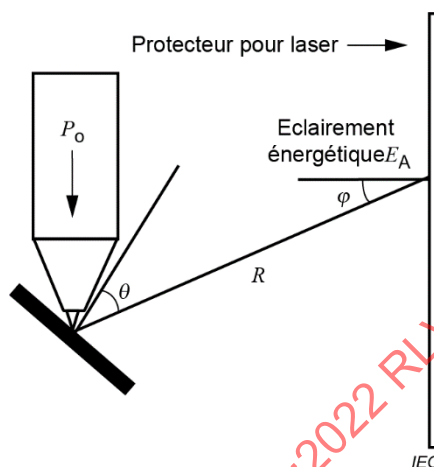


Figure B.1 – Calcul des réflexions diffuses

B.2.2 Réflexions spéculaires

Il est difficile de généraliser dans le cas de réflexions spéculaires.

Pour un faisceau laser circulaire symétrique avec une distribution gaussienne, la puissance P_o et le diamètre d_{86} au niveau de la lentille de focalisation, la longueur focale f , l'éclairement énergétique maximal (au centre de la distribution gaussienne) pour une distance R dans un plan normal à partir de la concentration est:

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

où ρ est la réflectivité de la surface de la pièce à traiter.

ATTENTION: Certaines surfaces courbées peuvent augmenter le danger de réflexion.

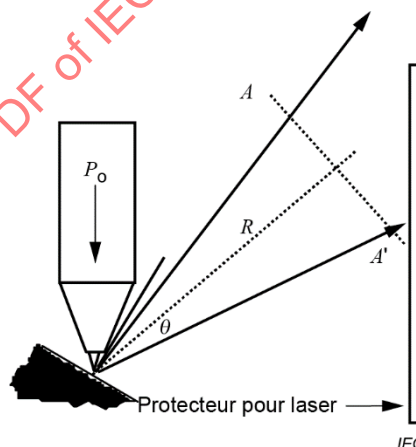


Figure B.2 – Calcul des réflexions spéculaires

B.3 Exemples de conditions d'évaluation

Il convient d'évaluer les LPE pour la ou les combinaisons les plus défavorables raisonnablement prévisibles de paramètres de laser disponibles, les matériaux de la pièce à traiter, la forme et les processus susceptibles de se produire en fonctionnement normal (l'IEC TR 60825-14 fournit des recommandations à l'intention des utilisateurs).

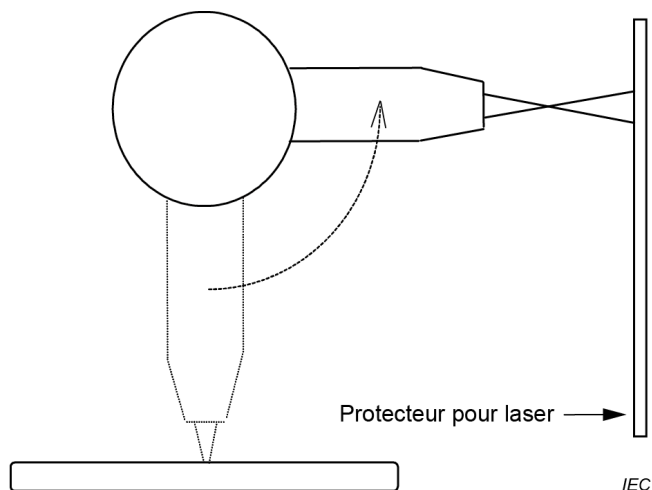


Figure B.3a – Défaillance du logiciel

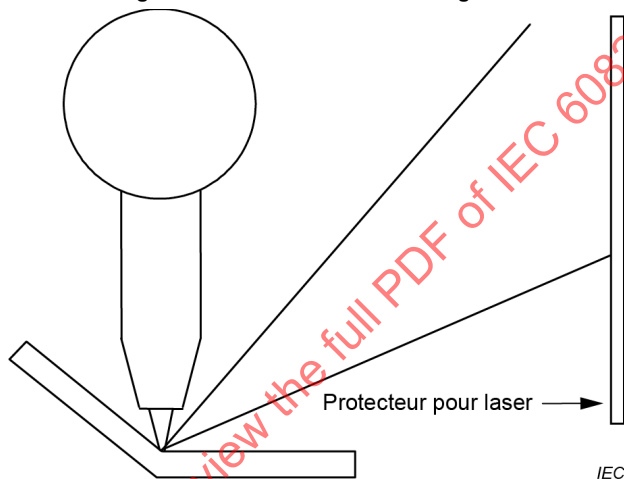


Figure B.3b – Pièce à traiter se courbant ou fixée de façon inadéquate

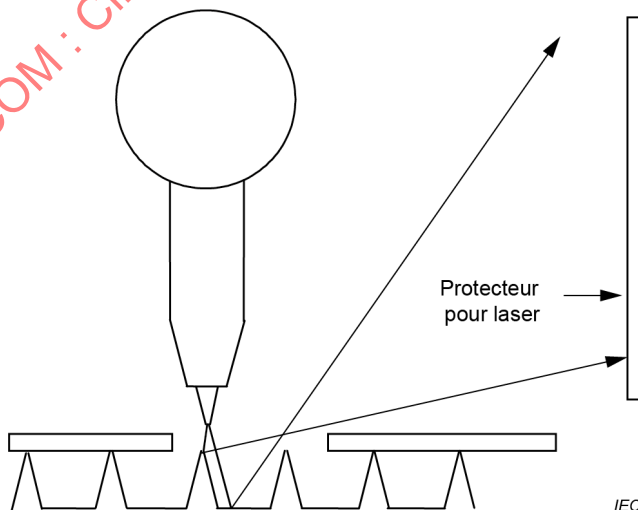


Figure B.3c – Absence de pièce à traiter

Figure B.3 – Quelques exemples de conditions de défauts prévisibles

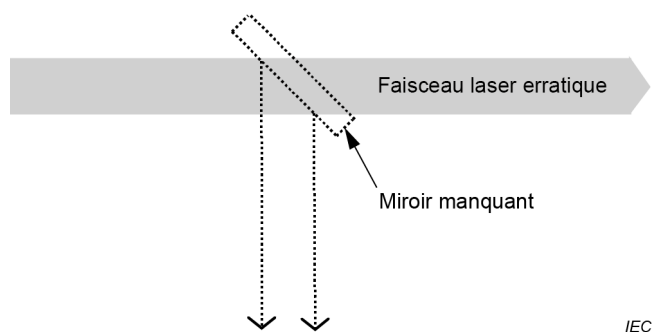


Figure B.4a – Laser mis en fonctionnement sans miroir de déflexion

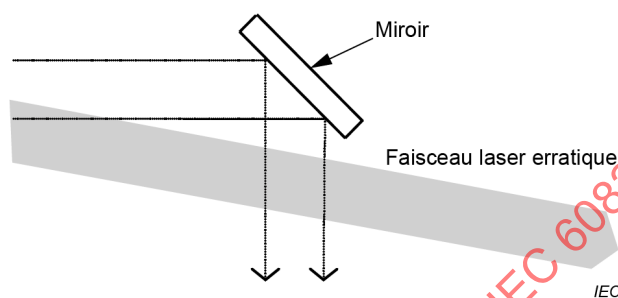


Figure B.4b – Faisceau décalé par rapport au miroir au cours de la procédure d'alignement

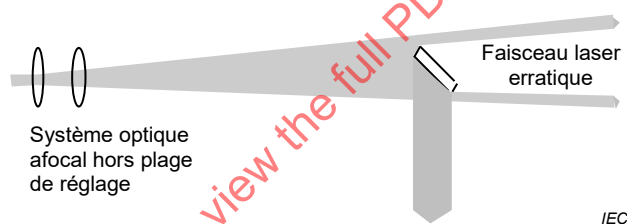


Figure B.4c – Faisceau se déployant au-delà de la plage optique

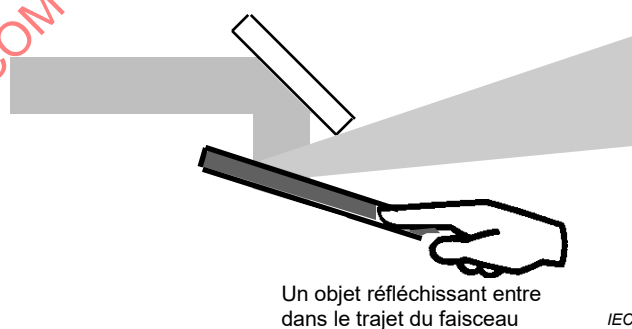


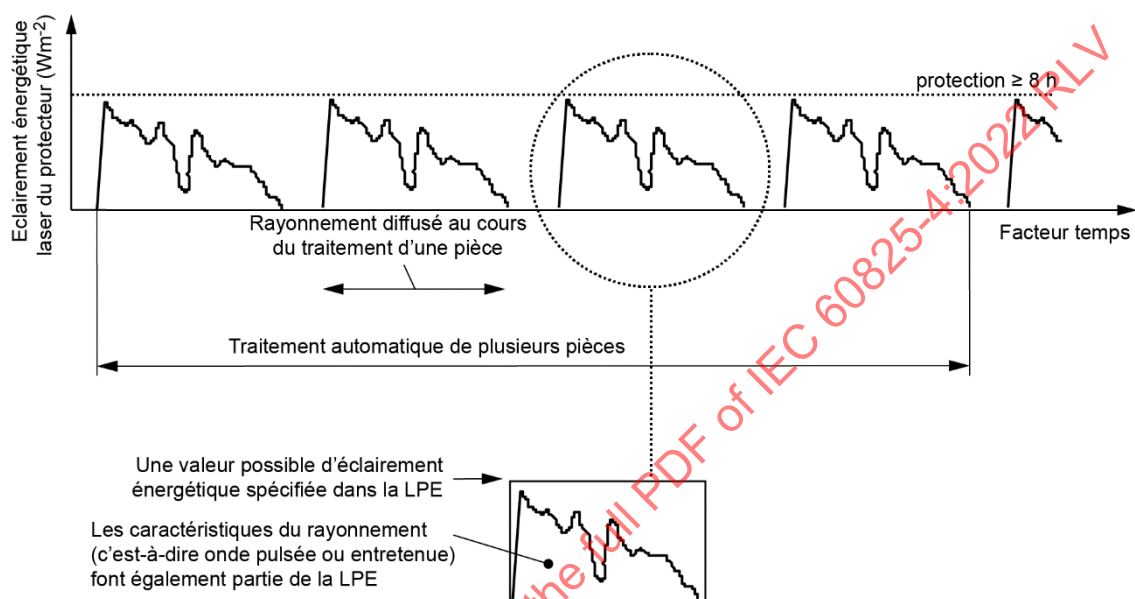
Figure B.4d – Objets réfléchissants interceptant le faisceau laser

Figure B.4 – Quatre exemples de faisceaux laser erratiques susceptibles de devoir être contenus par un protecteur temporaire dans des conditions d'entretien

B.4 Durée d'exposition

B.4.1 Fonctionnement normal

L'exposition d'un protecteur au rayonnement laser au cours d'un fonctionnement sans défaut peut comprendre des expositions à des niveaux faibles de rayonnement réfléchi, diffusé et transmis, qui sont répétées à chaque cycle de la machine. Dans ce cas, la LPE évaluée pour le fonctionnement sans défaut englobe la variation d'éclairement énergétique du protecteur au cours du cycle, voir la Figure B.5, répétée pour le nombre maximal de cycles de machine à l'intérieur d'un espacement des contrôles d'entretien de sécurité.



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Figure B.5 – Représentation de l'exposition du protecteur pour laser au cours du fonctionnement répétitif de la machine

B.4.2 Conditions de défaut

Un système de commande de sécurité impliquant une certaine forme de surveillance de la machine peut réduire le temps pendant lequel le protecteur doit contenir de façon sûre le danger de rayonnement dans des conditions de défaut. Deux exemples sont donnés à la Figure B.6.

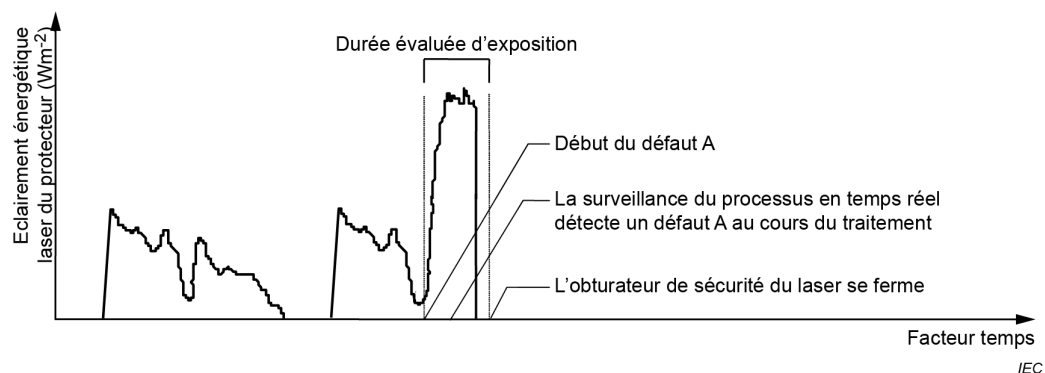


Figure B.6a – Arrêt avec une surveillance en temps réel de la sécurité de la machine

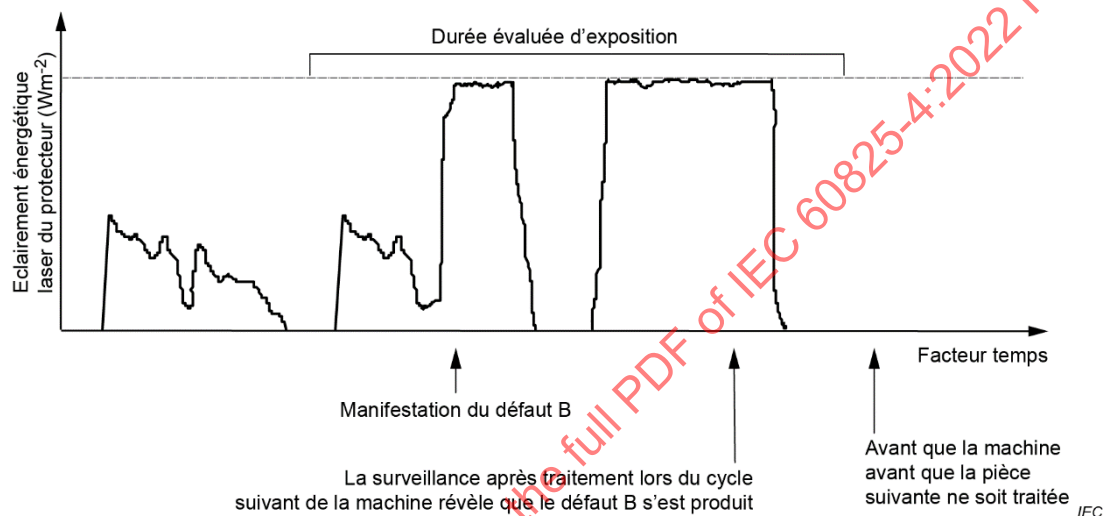


Figure B.6b – Arrêt avec une surveillance différée de la sécurité de la machine

Figure B.6 – Deux exemples de durée d'exposition évaluée

Pour des conditions de défaut raisonnablement prévisibles qui ne sont pas détectées par certains systèmes de commande liés à la sécurité, la durée d'exposition évaluée est l'espace complet des contrôles d'entretien de sécurité.

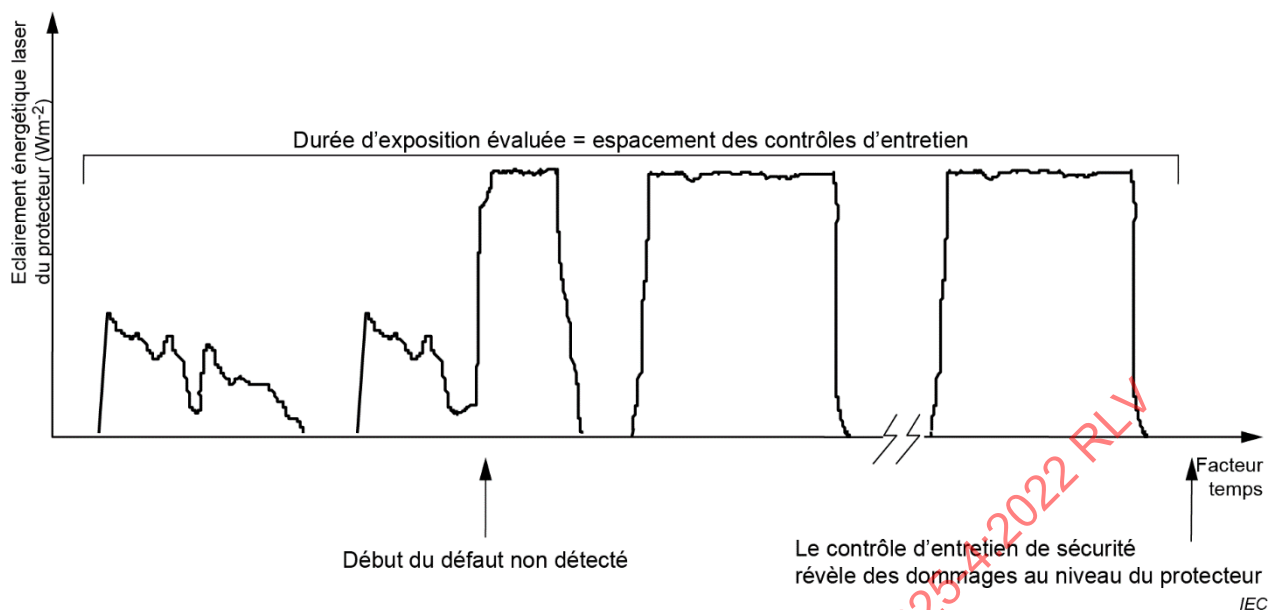


Figure B.7 – Durée d'exposition évaluée pour une machine sans aucun contrôle de sécurité

B.4.3 Opérations d'entretien

Les facteurs qui affectent directement le temps d'interruption de rayonnement laser mesuré à partir du début d'exposition d'un protecteur temporaire au cours des opérations d'entretien comprennent:

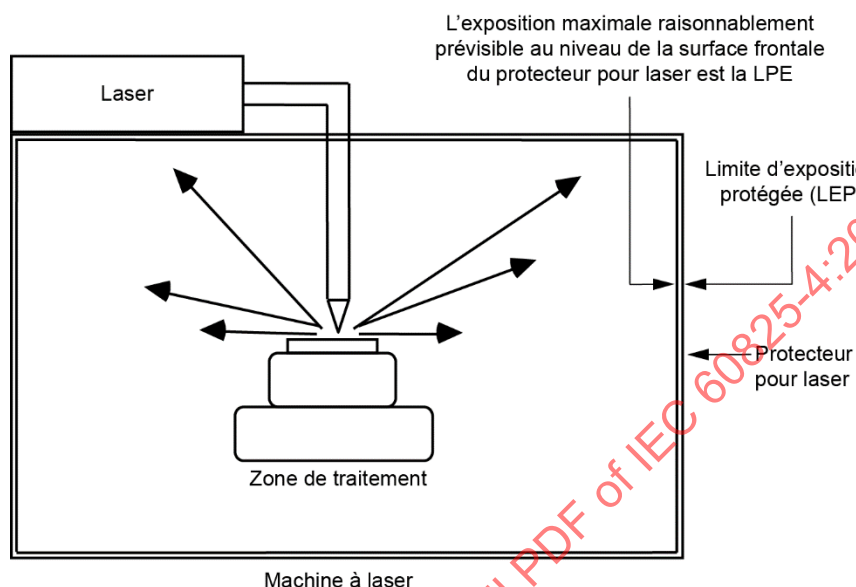
- l'utilisation d'un préréglage de la durée de fonctionnement du laser;
- le degré de contrôle des conditions de défaut;
- la mise à disposition de personnes pour surveiller l'état du protecteur (protecteurs passifs pour laser);
- la mise à disposition d'un contrôleur à action maintenue;
- le degré d'avertissement fourni par la réaction du protecteur à une exposition excessive à des rayonnements lasers (protecteurs passifs pour laser);
- le degré de dissimulation de la surface frontale du protecteur (protecteurs passifs pour laser);
- l'étendue totale du protecteur à protéger (protecteurs passifs pour laser);
- le degré de formation du personnel d'entretien.

Il convient de réaliser une appréciation du risque afin d'identifier les situations dangereuses et d'évaluer le niveau prévisible d'exposition. Lorsqu'une intervention humaine est exigée afin de limiter la durée d'exposition d'un protecteur temporaire, il convient d'utiliser une valeur d'au moins 10 s. Il convient de mettre en œuvre toutes les mesures de contrôle techniques et administratives raisonnablement réalisables afin de réduire le rôle des écrans temporaires dans la protection fournie.

Annexe C (informative)

Élaboration des termes définis

C.1 Distinction entre LPE et LEP



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Figure C.1 – Représentation de la protection autour d'une machine à laser

La limite prévisible d'exposition (LPE) à un emplacement particulier auquel un protecteur pour laser doit être situé est l'exposition maximale estimée par le fabricant de la machine à laser, évaluée dans des conditions normales et dans des conditions de défaut raisonnablement prévisibles, voir la Figure C.1. La valeur de la LPE définit la valeur minimale de la limite d'exposition protégée d'un protecteur pour laser qui peut être utilisée à cet emplacement.

La LEP indique la capacité d'un protecteur pour laser à protéger contre le rayonnement laser incident. Le fabricant de la machine à laser doit réaliser des essais afin de confirmer la capacité des protecteurs pour laser. Cela peut être réalisé par des essais directs, ou en déterminant la LEP du protecteur, ou en achetant un protecteur d'origine pour laser pour lequel la LEP est spécifiée.

C.2 Paramètres des protecteurs actifs

Un protecteur actif comprend deux composants essentiels:

- un écran physique, fortement atténuant pour la longueur d'onde du laser, qui agit comme un protecteur passif pour laser pour les faibles niveaux de rayonnement laser (par exemple, rayonnement à diffusion diffuse) et qui résiste à la pénétration de niveaux dangereux de rayonnement incident pendant une durée limitée (brève) uniquement;
- un système de commande de sécurité qui incorpore un capteur qui détecte les niveaux dangereux de rayonnement laser incident directement ou indirectement (par exemple, en mesurant la température ou en détectant certains autres effets induits par le rayonnement laser sur une certaine partie du protecteur pour laser) et émet ensuite un signal pour interrompre l'émission laser (par exemple, en coupant la chaîne d'interverrouillage de sécurité, mettant ainsi hors circuit la source laser, ou en fermant un obturateur de sécurité).

Les protecteurs pour laser sont fréquemment soumis à de faibles valeurs d'éclairement énergétique du laser en fonctionnement normal d'une machine à laser. Dans la mesure où le protecteur n'est pas menacé par un tel rayonnement, il convient que le capteur ne réagisse pas. En revanche, il convient de régler le capteur afin qu'il réagisse uniquement à un rayonnement laser incident qui dépasse une valeur de seuil pour laquelle l'intégrité du protecteur pour laser est menacée. Il y a un délai entre l'exposition à un rayonnement laser incident dépassant la valeur de seuil et le moment de production d'un signal d'interruption du protecteur actif par un protecteur actif pour laser, voir la Figure C.2. De façon similaire, il y a un délai, désigné par le temps d'interruption du laser, entre la production du signal d'interruption du protecteur actif et le moment de l'interruption du rayonnement laser.

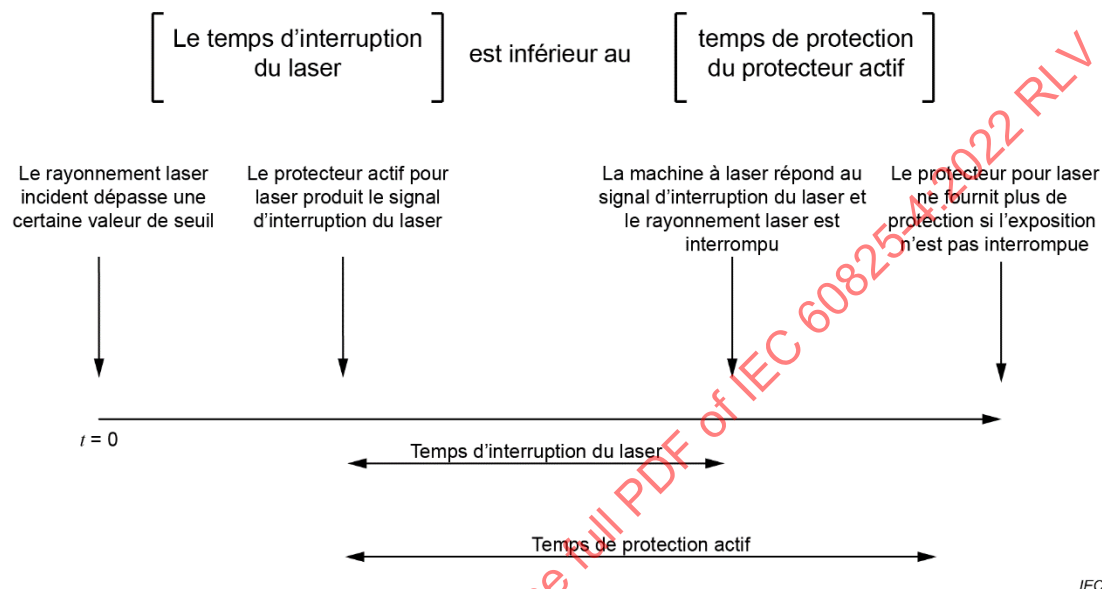


Figure C.2 – Représentation des paramètres des protecteurs actifs pour laser

Annexe D (normative)

Essais des protecteurs d'origine pour laser

D.1 Généralités

L'Annexe D comprend des informations détaillées relatives aux conditions d'essai à respecter et à la documentation à fournir par les fabricants de protecteurs d'origine pour laser.

Il convient de noter qu'il est inapproprié d'utiliser des lasers de puissance supérieure pour simuler les paramètres des lasers de faible puissance, ou d'utiliser des lasers de faible puissance pour simuler des paramètres des lasers de puissance élevée, par modification de l'éclairement énergétique ou par ajustement de la distance à partir du point focal, car la qualité de faisceau et les autres caractéristiques du faisceau laser sont susceptibles d'être différentes ou inattendues. La manipulation des caractéristiques des lasers d'un certain niveau de puissance pour faire ou extrapoler des estimations d'un laser d'un niveau différent (puissance supérieure ou inférieure) n'est pas admise.

La preuve des essais décrits ici s'applique uniquement aux paramètres lasers utilisés, auxquels elle est limitée. Il convient dès lors que les résultats de ces essais servent uniquement à des fins de comparaison des protecteurs pour laser.

La limite d'exposition protégée (LEP $W\ m^{-2}$) doit être applicable au protecteur, uniquement pour les dimensions des faisceaux utilisés dans les essais. Ces dimensions au niveau du protecteur doivent être indiquées par le fabricant des protecteurs pour laser car la LEP, qui oriente le choix du protecteur, diminue lorsque les dimensions du faisceau laser augmentent. Si la LEP est dépassée, le protecteur peut être endommagé et à terme se désintégrer. Pour les besoins de l'Annexe D, le temps de protection est l'intervalle de temps entre le rayonnement initial de la surface frontale et le moment auquel le rayonnement laser émettant au-delà de la surface arrière dépasse la limite d'émission accessible (LEA) de la classe 1, comme cela est défini dans l'IEC 60825-1.

Pour les niveaux de puissance supérieurs à 4 kW et pour un BPP inférieur à 4 mm·mrad, souvent, la densité de puissance absorbée n'augmente pas de façon linéaire. Il est cependant suggéré de suivre la procédure expérimentale décrite dans l'Annexe D pour déterminer le temps de protection pour la LEP souhaitée lorsque la puissance de sortie d'une combinaison de laser, de dispositif optique et de fibre optique est supérieure à 4 kW.

Il convient de faire preuve d'attention même à des puissances plus faibles lors de l'interprétation des résultats car l'apparition d'effets non linéaires ne peut être exclue ni ignorée. Il convient d'effectuer des essais à l'aide d'un montage d'essai optique qui correspond au système à laser tout entier pour lequel il est prévu d'utiliser les protecteurs.

D.2 Conditions d'essai

D.2.1 Précautions générales pour les conditions d'essai

Une variété d'essais de limite d'exposition avec différents matériaux et différents lasers peut entraîner des résultats non reproductibles, qui peuvent conduire à des interprétations erronées concernant la limite d'exposition protégée, et à des prévisions de durées de vie surestimées des protecteurs pour laser. Par conséquent, des conditions semblables et comparables pour des essais répétés doivent être assurées afin de maintenir l'intégrité des résultats.

Afin d'assurer l'intégrité des résultats, des efforts doivent être entrepris pour éliminer ou au moins réduire le plus possible les erreurs systématiques ou autres, qui peuvent également entraîner des interprétations erronées concernant la LEP ou une surestimation de la durée de vie du protecteur. De telles erreurs peuvent provenir des éléments suivants:

- a) matériau: surfaces réfléchissantes dont la réflectivité varie par l'oxydation ou la contamination;
- b) laser: avec des lasers de puissance élevée (par exemple, lasers de plusieurs kilowatts), en particulier ceux qui présentent une bonne qualité de faisceau (c'est-à-dire les lasers à fibre et les lasers à disque), des réactions ont été observées, mettant en évidence une influence considérable sur l'éclairement énergétique réel sur la surface des protecteurs pour laser.

Ainsi, au cours des essais, aucun effet mécanique ou physique (tel qu'il est décrit ci-dessous) ne doit se produire entre l'ouverture du faisceau et le point d'incidence sur le matériau du protecteur, ce qui peut nuire à une propriété optique quelconque. Les conditions d'essai doivent être reproduites avec exactitude. Dans le cas contraire, les temps de protection du protecteur passif qui en résultent peuvent ne pas être reproduits de manière fiable.

Les exemples d'effets qui influencent les résultats d'essai comprennent entre autres:

- la production d'une fine fumée métallique, au cours de laquelle le rayonnement laser est absorbé (par exemple, éblouissement thermique) ou diffusé (par exemple, effet Mie) dans la fumée métallique;
- la variation du point focal (décalage focal induit thermiquement), au cours de laquelle il y a une variation de la densité de puissance au niveau de la surface du protecteur pour laser. Ces effets peuvent réduire la puissance du laser sur l'échantillon en essai;
- l'établissement d'un équilibre (c'est-à-dire équilibre thermique ou équilibre entre rayonnement incident et réfléchi ou réémis) qui entraîne un temps de protection du protecteur passif pratiquement infini en un essai, tandis qu'un essai répété dans des conditions réputées égales entraîne une LEP ou un temps de protection fini(e).

La limite d'exposition soumise à l'essai (W m^{-2} pour les lasers à onde entretenue ou J m^{-2} pour les lasers à impulsions) doit être déterminée par les essais réalisés lors de l'irradiation de la surface de chaque échantillon dans un lot d'au moins dix. Chaque échantillon doit être d'épaisseur, de composition et de fini de surface représentatifs, ayant une surface d'essai frontale préparée pour donner l'absorption la plus défavorable de rayonnement laser. Les dimensions de ces échantillons doivent être au moins égales à trois fois le diamètre du faisceau mesuré aux endroits auxquels la distribution de l'intensité a diminué pour atteindre une valeur de $1/e^2$ de la valeur de crête à l'emplacement de l'exposition (garantissant de ce fait que le flux de chaleur rayonnante est pris en compte). Des éléments de liaison structurels doivent être inclus dans les essais uniquement s'ils sont nécessaires pour s'assurer de la construction et de l'intégrité du protecteur. Dans le cas de faisceaux non circulaires, la forme du faisceau utilisé pour l'essai doit être spécifiée. Les faisceaux non circulaires sont ceux pour lesquels la différence entre la dimension la plus grande et la dimension la plus petite est supérieure à 10 %. Les essais doivent être réalisés à la fois en mode à impulsions et en mode à onde entretenue, lorsque ces modes de fonctionnement du laser sont possibles, dans la mesure où le rayonnement impulsif peut conduire à différents résultats.

Il convient que les paramètres du rayonnement impulsif utilisés dans ces essais soient représentatifs des paramètres à utiliser dans toute application spécifiée.

La forme du faisceau d'essai doit être spécifiée car elle affecte la répartition de la chaleur dans l'échantillon.

Il convient de prendre des précautions particulières dans la préparation des échantillons lors des essais des protecteurs pour laser qui utilisent de l'aluminium, du cuivre, de l'acier inoxydable et des matériaux avec des surfaces à revêtement en zinc. Il a été observé pour ces matériaux et d'autres matériaux similaires, que la LEP et le temps de protection dépendent fortement de la préparation des échantillons et du montage expérimental qui affecte la répétabilité des mesurages de LEP et du temps de protection.

Il convient que l'absorption la plus défavorable prenne en compte la réflectivité du matériau du protecteur et les variations à la surface du matériau du protecteur pour laser pendant la durée de vie prévisible du protecteur pour laser. Toutefois, il convient de ne pas avoir préalablement traité la plaque d'essai d'aucune manière possible qui puisse altérer artificiellement les conditions d'absorption, à l'exception des modifications de réflectivité naturelles accélérées du matériau du protecteur, raisonnablement attendues sur la durée de vie prévisible du protecteur pour laser. Il convient de réaliser l'essai de qualification dans des conditions normales pour la protection laser.

Si un support d'échantillon est nécessaire pour les essais, son empiètement maximal sur le bord de l'échantillon ne doit alors pas dépasser 3 mm à partir du bord de l'échantillon. La partie du dispositif de maintien en contact avec l'échantillon doit être en matériau thermiquement isolant (par exemple, en céramique) compatible avec une utilisation aux températures générées.

L'échantillon doit être perpendiculaire (ou incliné à pas plus de $\pm 3^\circ$ pour éviter les réflexions en retour) au faisceau laser, et l'axe du faisceau doit être centré sur l'échantillon à une distance F_1 représentée à la Figure D.1. La distance F_1 au-delà du point focal ne doit pas être supérieure à trois fois la longueur focale (F) de la lentille de focalisation. Si, pour une application spécifique, le protecteur doit être positionné à une distance inférieure à trois fois la longueur focale (F) à distance du point focal, la distance minimale entre le point focal et le protecteur doit être considérée comme la distance F_1 .

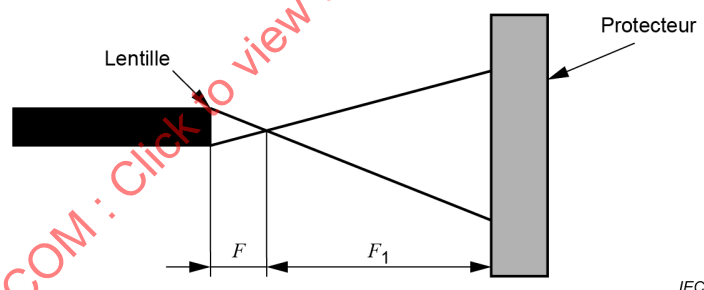


Figure D.1 – Schéma simplifié de la disposition pour l'essai

Il convient d'effectuer l'essai avec le faisceau orienté horizontalement, tel qu'il est représenté à la Figure D.1. Si une orientation différente du faisceau a été utilisée, indiquer dans le rapport de qualification la disposition de l'essai concernant l'orientation du faisceau.

La surface de l'échantillon en essai doit être suffisamment ventilée (par exemple, ventilation cross jet) pour assurer que la surface d'essai et l'espace entre l'échantillon d'essai et le système optique de conformation du faisceau restent exempts de débris, de fumées, etc. au cours de la période de l'essai. La ventilation doit avoir le même effet que la circulation d'air dans l'application prévue.

De plus, lorsque l'échantillon de protecteur comporte des couches multiples, toutes les surfaces internes et les espaces internes doivent être suffisamment ventilés (par exemple, ventilation cross jet, voir la Figure D.2), pour assurer que toutes les surfaces restent exemptes de débris, de fumées, etc. au cours de la période de l'essai.

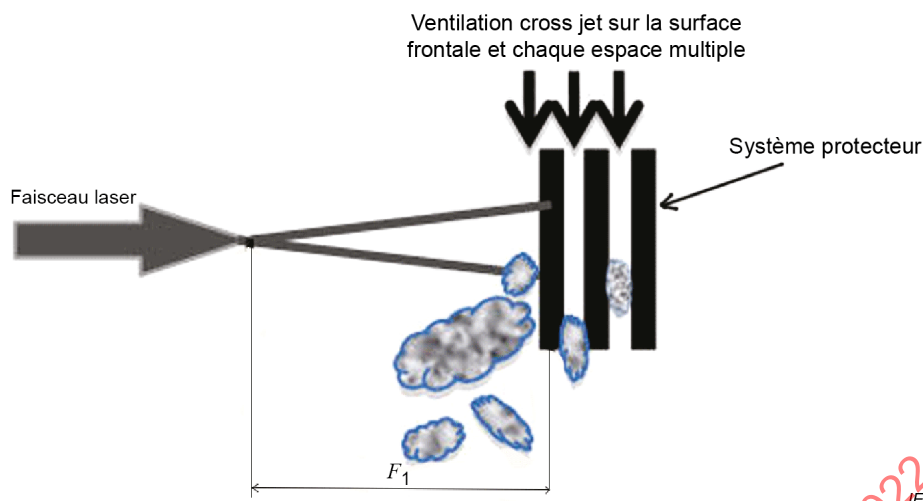


Figure D.2 – Schéma simplifié de la ventilation pour le protecteur en essai

D.2.2 Conditions d'essai pour protecteurs passifs pour laser

Pour les protecteurs passifs pour laser, le rayonnement laser accessible au niveau de la surface arrière de l'échantillon ne doit pas dépasser la LEA de la classe 1 au cours de l'exposition d'essai, dont la durée dépend de la période d'exposition établie par le fabricant du protecteur d'origine. Le temps de protection du protecteur doit dépasser l'espacement des contrôles d'entretien, tel qu'il est défini dans le Tableau D.1, selon l'utilisation prévue du protecteur pour laser.

Il convient que les fabricants des protecteurs d'origine pour laser spécifient les espacements des contrôles d'entretien correspondants, en utilisant les classifications d'essai T1, T2 ou T3 définies dans le Tableau D.1. L'espacement des contrôles d'entretien représente l'intervalle de temps au-delà duquel le protecteur est complètement contrôlé et vérifié pour mettre en évidence l'absence de dommages ou de détériorations. Ceci est destiné à garantir que le protecteur est dans un état qui peut tolérer une exposition à un rayonnement laser pendant un intervalle de maintenance supplémentaire.

Tableau D.1 – Classification d'essai des protecteurs pour laser

Classification d'essai	Espacement des contrôles d'entretien	Utilisation suggérée des protecteurs pour laser
T1	30 000	Pour usage sur des machines automatiques
T2	100	Pour fonctionnement en cycle court et contrôle intermittent
T3	10	Pour contrôle continu par observation

D.2.3 Exigences relatives aux protecteurs actifs

Pour les protecteurs actifs, les exigences suivantes s'appliquent.

- Si le protecteur actif fait partie d'un système de commande lié à la sécurité d'une machine, la norme applicable et appropriée pour les systèmes de commande liés à la sécurité doit être appliquée.

- b) Le protecteur actif pour laser doit déclencher le signal d'interruption du laser (qui est prévu pour entraîner l'interruption automatique du rayonnement laser) en réponse à toute exposition de sa surface frontale au rayonnement laser au-delà de l'exposition spécifiée (niveau et durée). Un défaut raisonnablement prévisible au sein du système du protecteur actif ne doit pas entraîner la perte de la fonction de sécurité. Un défaut raisonnablement prévisible d'un élément du protecteur doit être détecté antérieurement à ou lors du recours à la fonction de sécurité.
- c) Le rayonnement laser accessible à la surface arrière d'un échantillon du protecteur passif pour laser, incorporé dans le protecteur actif pour laser, ne doit pas dépasser la LEA de la classe 1 en réponse à une exposition de sa surface frontale au rayonnement laser, quelle qu'elle soit jusqu'à et y compris l'exposition spécifiée pendant une durée supérieure au temps de protection spécifié du protecteur actif (tel qu'il est défini en 3.2).
- d) Si des vérifications de fonctionnalité automatique au sein du système de protecteur actif sont effectuées au cours des périodes d'émission laser, qui interrompent temporairement le fonctionnement du système de protecteur actif pour laser, le temps cumulé pris pour effectuer ces vérifications doit prendre en compte l'effet de toutes les impulsions laser répétitives, et ne doit pas dépasser le temps de protection du protecteur actif ni causer de réduction des performances globales du protecteur actif pour laser.
- e) Le fonctionnement d'un protecteur actif dépend des variations des paramètres physiques qui provoquent le déclenchement du signal d'interruption du protecteur actif. Le protecteur actif doit être surveillé en continu au cours de la période d'exposition potentielle du laser. À d'autres périodes, le protecteur actif ne doit pas être affecté par les variations des paramètres (par exemple, fumée, humidité, vibrations ou chocs, variations de température) et toute autre variation de l'environnement, empêchant ainsi le protecteur actif d'être désactivé par inadvertance.
- f) Tout dommage sur le protecteur actif doit être détecté antérieurement à ou lors du recours à une protection et, jusqu'à ce que ce dommage ait été rectifié, tout fonctionnement ultérieur doit être évité.

D.3 Temps de protection correspondant à la limite d'exposition protégée (LEP) spécifiée

Le temps de protection du protecteur passif qui correspond à la limite d'exposition protégée (LEP) (telle qu'elle est définie en 3.21) doit être déterminé à partir des résultats obtenus lors des mesurages réalisés. La densité de puissance expérimentale du laser irradié doit être ajustée afin d'être supérieure ou égale à la limite d'exposition protégée (LEP). Lors du calcul du temps de protection à partir des données échantillonnées, le théorème de la limite centrale doit être appliqué en partant de l'hypothèse d'une distribution normale sous-jacente.

Les échantillons individuels en provenance d'un lot soumis à l'essai qui ne connaissent pas de brûlure perforante au cours de l'essai doivent être ignorés d'un point de vue statistique, sauf si le lot complet n'a pas subi une telle brûlure.

Un niveau de confiance de 99 % est exigé et est assuré en utilisant $\pm 3\sigma$, où σ est l'écart-type dans la distribution normale, donné par

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

où

$p(x)$ est la probabilité de x ;

x est la valeur individuelle d'un échantillon; et

μ est la moyenne du temps expérimental pour brûlure perforante des échantillons à l'essai, à l'exception des protecteurs pour laser en polymère renforcé de fibres de carbone (PRFC) type d'emplacement et en matériaux similaires. Concernant les protecteurs pour laser en PRFC type d'emplacement, μ doit être défini comme la moyenne du temps

expérimental d'allumage de la face arrière lorsqu'il est plus court que le temps expérimental pour brûlure perforante.

Si la valeur arithmétique de la moyenne des temps pour brûlure perforante mesurés pour les échantillons à l'essai moins 3σ est un nombre négatif, cette valeur doit être égale à zéro.

NOTE 1 Dans ces essais appliqués en particulier aux matériaux avec des surfaces réfléchissantes et/ou un point de fusion faible (par exemple, l'aluminium), les effets non linéaires peuvent se traduire par une valeur négative pour 3σ . Ces effets non linéaires peuvent aussi indiquer à tort une distance plus courte entre le foyer et la surface de l'échantillon qui est principalement due aux propriétés réfléchissantes (ou de miroir) du matériau de l'échantillon.

La LEP citée pour le temps de protection passif doit être la densité de puissance du laser réelle utilisée dans l'essai de mesure du temps de protection passif ou elle doit être déterminée entre deux points de mesure.

Le temps de protection doit être égal à $0,7 \times (\mu - 3\sigma)$ s.

NOTE 2 Le facteur 0,7 mentionné dans l'équation pour la LEP et le temps de protection est introduit comme un facteur de sécurité supplémentaire.

NOTE 3 Les échantillons sont choisis de façon aléatoire dans une population de base.

D.4 Informations fournies par le fabricant

Le fabricant doit fournir avec l'ensemble des données d'échantillons d'essai au moins les informations suivantes:

- a) le nom et l'adresse de l'organisme qui réalise les essais;
- b) le numéro du présent document (IEC 60825-4);
- c) le matériau et sa spécification ou un étalon reconnu au niveau international conformément auquel il est réalisé ou assigné, utilisés pour les échantillons. Les précisions relatives au traitement à chaud, au durcissement, au fini des surfaces ou à tout autre processus appliqué au matériau, doivent être incluses dans cette spécification;
- d) le nombre d'échantillons utilisés lors des essais;
- e) les informations détaillées relatives aux paramètres des lasers utilisés, comprenant au moins
 - 1) la ou les longueurs d'onde du laser;
 - 2) la puissance ou l'énergie (en spécifiant la valeur de crête ou la valeur moyenne) à laquelle les essais ont été réalisés;
 - 3) la durée d'impulsion et la fréquence de répétition des impulsions (pour les essais qui utilisent un laser à impulsions);
 - 4) le diamètre du faisceau ($1/e^2$) à l'entrée de la lentille de focalisation;
 - 5) le produit de caractérisation des paramètres du faisceau (mm·mrad);
 - 6) la forme de la section transversale du faisceau au niveau du foyer; et
 - 7) un mesurage de l'exposition ou de l'éclairement énergétique du faisceau au niveau de la surface en essai;
- f) la longueur focale de la lentille de focalisation utilisée lors des essais;
- g) la distance F_1 ;
- h) l'espacement des contrôles d'entretien applicable au protecteur pour laser;
- i) les temps de protection et la LEP qui en résultent, avec tous les calculs et toutes les analyses statistiques réalisés.

Annexe E (informative)

Lignes directrices pour le montage et l'installation des protecteurs pour laser

E.1 Présentation

L'Annexe E étudie le montage et l'installation des protecteurs destinés à protéger le personnel contre les dangers des rayonnements lasers autour de la zone de traitement d'une machine de traitement par laser des matériaux. Ces lignes directrices sont destinées à être utilisées par les fabricants et/ou les utilisateurs. L'Annexe E a pour objet d'englober une protection pour une machine à laser autonome (voir l'ISO 11553-1) et une protection supplémentaire (souvent installée par l'utilisateur) exigée pour intégrer de façon sûre une machine à laser. Les questions de protection relatives aux dangers associés au traitement par laser (qui incluent les dangers mécaniques, électriques, de fumée et de rayonnement secondaire) ne sont pas prises en considération de façon détaillée dans l'Annexe E.

E.2 Généralités

E.2.1 Exigences

Les protecteurs pour laser sont exigés pour isoler les dangers présentés par les lasers en plus des dangers associés au traitement par laser. Certains des protecteurs peuvent faire partie intégrante d'une machine à laser et une protection supplémentaire peut être utilisée afin de faciliter un chargement et un déchargement en toute sécurité des pièces à traiter ainsi que pour l'entretien.

E.2.2 Montage des protecteurs

Les éléments clés dans l'évaluation du montage et de l'installation des protecteurs autour de la zone de traitement comprennent:

- a) le degré d'accessibilité exigé pour la manipulation des pièces à traiter (en particulier le degré de manipulation manuelle);
- b) la méthode de fixation de la pièce à traiter (par exemple, utilisation de bâtis et de pinces);
- c) la méthode de retrait de la pièce à traiter et de toutes les parties associées (par exemple, débris) après le traitement.

E.2.3 Emplacement des protecteurs

Une bonne pratique dans la détermination de l'emplacement des protecteurs pour laser comprend les éléments suivants:

- a) il convient de placer le protecteur pour laser à au moins trois longueurs focales du point de focalisation d'une lentille de focalisation lorsque cela est possible;
- b) il convient de ne pas placer les protecteurs pour laser avec des limites d'exposition protégée (LEP) plus faibles, par exemple les fenêtres d'observation, aux endroits auxquels le faisceau direct ou des réflexions spéculaires sont prévus.

E.2.4 Enveloppe complète

Une enveloppe complète est une enveloppe qui satisfait à toutes les exigences relatives à un capot de protection, comme cela est spécifié en 6.2.1 de l'IEC 60825-1:2014 et englobe le laser incorporé et l'ensemble de la zone de traitement, de sorte qu'il n'y ait aucun accès humain à des rayonnements dangereux.

E.2.5 Enveloppe incomplète

Une enveloppe incomplète est une enveloppe qui ne prévoit pas un capot de protection complet englobant le laser incorporé et l'ensemble de la zone de traitement, de sorte qu'un accès humain à des rayonnements dangereux est possible.

Si le risque d'exposition n'est pas tolérable (pour les personnes qui peuvent se trouver sur des passerelles ou des plates-formes qui les élèvent au-dessus des protecteurs d'une machine dont la face supérieure est ouverte), des mesures de contrôle supplémentaires sont exigées.

E.2.6 Hiérarchie du contrôle des zones dangereuses laser

La hiérarchie suivante de mesures est recommandée pour maintenir les personnes hors d'une zone dans laquelle il existe un risque intolérable:

- a) mise en place d'un protecteur fixe;
- b) mise en place d'un protecteur amovible;
- c) mise en place d'un dispositif de protection électronique attaché à la chaîne d'interverrouillage de sécurité de la machine, autour du périmètre de la zone (par exemple, un détecteur de faisceau lumineux) ou sur la zone (par exemple, un tapis sensible à la pression);
- d) mise à disposition d'un écran physique, ainsi que des informations, des instructions, de la formation, d'une surveillance;
- e) prévoir un moyen qui rend possible l'utilisation, l'opérateur étant situé à une certaine distance de la zone de traitement, ainsi que des équipements de protection individuelle (EPI).

NOTE Les mesures (c) et (d) ne prévoient aucune protection contre le rayonnement laser émis par la machine laser, et par conséquent peuvent uniquement être prises en considération lorsque la distance entre la zone contrôlée et les ouvertures dans la machine dépasse la distance nominale de risque oculaire (DNRO).

E.2.7 Équipements de protection individuelle

Il convient de n'utiliser les équipements de protection individuelle qu'en dernier recours, lorsqu'une combinaison de mesures techniques et administratives ne peut prévoir raisonnablement un niveau suffisant de protection. Lorsque les équipements de protection individuelle sont utilisés, il convient qu'ils soient accompagnés d'un niveau adéquat de mesures administratives régissant leur utilisation. Il convient de ne les utiliser que lorsqu'une appréciation du risque a indiqué que l'utilisation d'autres moyens de réduction des risques n'est pas parvenue à produire un degré suffisant de sécurité et lorsqu'il n'est pas raisonnablement possible d'assurer une protection adéquate par d'autres moyens. En travaillant au contact d'Ultraviolet B (de 290 nm à 320 nm) et d'Ultraviolet C (de 100 nm à 90 nm) des vêtements de protection peuvent être exigés.

E.2.8 Intervention humaine

Lorsque le fonctionnement de la machine exige un accès humain, l'intervention humaine peut alors être comprise dans l'appréciation du risque en tenant compte des implications pendant la durée de la condition de défaut. Dans ces conditions, il convient de contrôler l'accès et de ne le rendre accessible qu'à des personnes autorisées ayant reçu une formation adéquate à la sécurité laser et à l'entretien du système laser impliqué. Il convient également que la zone soit d'accès limité, fermée au public, et que les observateurs ou autres personnels non formés ne soient pas exposés aux dangers au moyen de protecteurs ou de mesures administratives.