INTERNATIONAL STANDARD

IEC 60825-4

Edition 1.2

2003-10

Edition 1:1997 consolidated with amendments 1:2002 and 2:2003

Safety of laser products –

Part 4: Laser guards

Sécurité des appareils à laser –

Partie 4: Barrières laser

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SAFETY OF LASER PRODUCTS –

Part 4: Laser guards

FOREWORD

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

This consolidated version of IEC 60825-4 is based on the first edition (1997) [documents 76/159/FDIS and 76/168/RVD], its amendment 1 (2002) [documents 76/242/FDIS and 76/252/RVD] and its amendment 2 (2003) [documents 76/263/FDIS and 76/273/RVD].

It bears the edition number 1.2.

A vertical line in the margin shows where the base publication has been modified by amendments 1 and 2.

Annex D forms an integral part of this standard.

Annexes A, B, C and E are for information only.

The French version of this standard will be issued separately.

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

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- withdrawn;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

INTRODUCTION

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

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

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

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

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

SAFETY OF LASER PRODUCTS –

Part 4: Laser guards

1 General

1.1 Scope

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

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

In addition this part of IEC 60825 indicates:

a) how to assess and specify the protective properties of a laser guard; and

b) how to select a laser guard.

1.2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1: 1993, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide*

ISO/TR12100-1: 1992, *Safety of machinery – Basic concepts, general principles for design – Part 1: Basic terminology, methodology*

ISO/TR12100-2: 1992, *Safety of machinery – Basic concepts, general principles for design – Part 2: Technical principles and specifications*

ISO 11553: 1996, *Safety of machinery – Laser processing machines – Safety requirements*

1.3 Definitions

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

1.3.1
active guard protection time
for a given laser exposure of the front surface of an active laser guard, the minimum time, measured from the issue of an active guard termination signal, for which the active laser guard can safely prevent laser radiation accessible at its rear surface from exceeding the class 1 AEL.

1.3.2
active guard termination signal
the signal issued by an active guard in response to an excess exposure of its front surface to laser radiation and which is intended to lead to automatic termination of the laser radiation

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

1.3.3
active laser guard
a laser guard which is part of a safety-related control system. The control system generates an active guard termination signal in response to the effect of laser radiation on the front surface of the laser guard

1.3.4
foreseeable exposure limit (FEL)
the maximum laser exposure on the front surface of the laser guard, within the maintenance inspection interval, assessed under normal and reasonably foreseeable fault conditions

1.3.5
front surface
the face of the laser guard intended for exposure to laser radiation

1.3.6
laser guard
a physical barrier which limits the extent of a danger zone by preventing laser radiation accessible at its rear surface from exceeding the class 1 AEL

1.3.7
laser processing machine
a machine which uses a laser to process materials and is within the scope of ISO 11553

1.3.8
laser termination time
the maximum time taken, from generation of an active guard termination signal, for the laser radiation to be terminated

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

1.3.9
maintenance inspection interval
the time between successive safety maintenance inspections of a laser guard

1.3.10
passive laser guard
a laser guard which relies for its operation on its physical properties only

1.3.11
process zone
the zone where the laser beam interacts with the material to be processed

1.3.12
proprietary laser guard
a passive or active laser guard, offered by its manufacturer as a guard with a specified protective exposure limit

1.3.13
protective exposure limit (PEL)
the maximum laser exposure of the front surface of a laser guard which is specified to prevent laser radiation accessible at its rear surface from exceeding the class 1 AEL

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

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

1.3.14
rear surface
any surface of a laser guard that is remote from the associated laser radiation and usually accessible to the user

1.3.15
reasonably foreseeable
an event (or condition) when it is credible and its likelihood of occurrence (or existence) cannot be disregarded

1.3.16
safety maintenance inspection
documented inspection performed in accordance with manufacturer's instructions

1.3.17
temporary laser guard
a substitute or supplementary active or passive laser guard intended to limit the extent of the danger zone during some service operations of the laser processing machine

2 Laser processing machines

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

2.1 Design requirements

A laser guard shall satisfy ISO/TR 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.

2.1.1 General requirements

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

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

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

2.1.2 Consumable parts of laser guards

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

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

2.2 Performance requirements

2.2.1 General

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

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

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

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

2.2.2 Active laser guards

a) The active guard protection time shall exceed the laser termination time up to the foreseeable exposure limits.

b) The generation of an active guard termination signal shall give rise to a visible or audible warning. A manual reset is required before laser emission can recommence.

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

2.3 Validation

If the laser processing machine manufacturer chooses to make a laser guard, the manufacturer shall confirm that the guard complies with the design requirements of 2.1 and can satisfy the performance requirements set out in 2.2.

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

2.3.1 Validation of performance

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

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

NOTE 2 See annex B for the assessment of FEL.

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

a) by calculating or measuring the exposure and reproducing the conditions; or

b) without quantifying the FEL, by creating the machine conditions under which the FEL is produced.

The condition of the laser guard or sample shall be such as to replicate those physical conditions of the front surface permitted within the scope of the routine inspection instructions and within the service life of the guard, which minimize the laser radiation protective properties of the laser guard (for example wear and tear and surface contamination) (see 2.4.2).

2.4 User information

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

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

3 Proprietary laser guards

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

3.1 Design requirements

A proprietary laser guard shall not create any associated hazard at or beyond its rear surface when exposed to laser radiation up to the specified PEL when used as specified in the user information (see 3.6).

3.2 Performance requirements

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

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

3.3 Specification requirements

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

a) the magnitude and variation with time of irradiance or radiant exposure at the front surface of the laser guard (in units of Wm^{-2} or Jm^{-2} respectively), specifying any upper limit to the area of exposure;

b) the overall duration of exposure under these conditions;

c) the wavelength for which this PEL applies;

d) the angle of incidence and (if relevant) the polarization of the incident laser radiation;

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

f) for an active laser guard, the active guard protection time.

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

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

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

3.4 Test requirements

3.4.1 General

Testing shall be performed using the complete laser guard or an appropriate sample of the material used to construct the guard. In either case, the condition of the guard or sample shall be such as to replicate or exceed the worst permissible physical condition of the front surface, including reduced surface reflection and damage permitted within the scope of the routine maintenance instructions (see 3.6).

The front surface irradiation shall be either as specified by the PEL or, in the case of sample testing, as specified in 3.4.2 below.

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

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

3.4.2 Sample testing

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

3.5 Labelling requirements

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

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

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

3.5.4 The labelling shall state the full PEL specification.

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

3.6 User information

In addition to the specifications listed in 3.3, the following information shall be supplied to the user by the manufacturer of a proprietary laser guard:

a) a description of the permitted uses of the laser guard;

b) a description of the form of mounting and connection of the laser guard;

c) information on the installation of the laser guard – for active laser guards this shall include interface and supply requirements for the guard;

d) maintenance requirements, including for example details of inspection and test procedures, cleaning, replacement or repair of damaged parts;

e) instructions, that after any actuation of the safety control system of an active guard, the cause shall be investigated, checks shall be made for damage, and the necessary remedial action to be taken before resetting the control system;

f) the labels in 3.5 and their locations. If only part of the front surface of the guard is a laser guard, this area shall be identified;

g) a statement of compliance with this standard.

Annex A
(informative)

General guidance on the design and selection of laser guards

A.1 Design of laser guards

A.1.1 Passive laser guards

Examples of a passive laser guard include the following.

a) A metal panel relying on thermal conduction, if necessary enhanced by forced air or water cooling, to maintain the surface temperature below its melting point under normal and reasonably foreseeable fault conditions.

b) A transparent sheet, opaque at the laser wavelength, which is unaffected by low value of laser exposure under normal operation of the laser processing machine.

A.1.2 Active laser guards

Examples of an active laser guards include the following.

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

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

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

A.1.3 Hazard indication (passive guards)

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

A.1.4 Power supply (active guards)

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

A.2 Selection of laser guards

A simple selection process is as follows:

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

b) if necessary, minimize the FEL under fault conditions, preferably by including automatic monitoring in the machine which will detect the fault conditions and limit the exposure time. Examples of alternatives include the following:

   – ensure that the laser guard is sufficiently far away from beam focus produced by focusing optics;

   – install vulnerable parts of laser guard (such as viewing windows) away from regions that could be exposed to high irradiance;

– move the laser guard farther away from the laser process zone;
– required in the essential servicing documentation for temporary laser guards, additions such as:
  - one or more persons to be present to supervize the condition of the front surface of the laser guard, to reduce the assessed exposure duration of a passive guard;
  - a hold-to-operate controller to be used by the person(s) supervising the condition of the front surface of the laser guard, to reduce the assessed exposure duration of a passive guard;
  - additional local temporary guarding, apertures and beam dumps to be employed, to absorb any powerful errant laser beams;
  - the danger zone to be bounded by errant beam warning devices and the guard placed beyond this zone to reduce the assessed exposure duration;
– incorporate in the design of the machine, when using temporary laser guards, beam control features to facilitate improved laser beam control during servicing operations, such as:
  - holders for precise location of additional beam forming components (for example turning mirrors) required during servicing;
  - mounts which allow only limited scope for beam steering.

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

A.2.1 Option 1: passive laser guard

This is the simplest option.

NOTE Design and quality control are particularly important considerations where the absorption at the laser wavelength is dominated by a minority additive, such as a dye in a plastic. In such cases, where the manufacturer of the material does not specify the concentration of the absorber or the material optical attenuation at the laser wavelength, samples from the same batch of the material should first be tested as described in 2.3.1.

A.2.2 Option 2: active laser guard

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

A.2.3 Option 3: proprietary laser guard

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

Annex B
(informative)

Assessment of foreseeable exposure limit

B.1 General

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

The standard prEN 1050 provides a general methodology for risk assessment. The assessment should include consideration of cumulative exposure in normal operation (for example during each part processing cycle of the machine) over the maintenance inspection interval.

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

The full specification of an FEL comprises the following information.

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

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

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

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

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

d) The full duration of exposure.

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

e) The wavelength of the radiation.

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

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

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

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

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

B.2 Reflection of laser radiation

B.2.1 Diffuse reflections

Assuming a Lambertian reflector with 100 % reflectivity

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

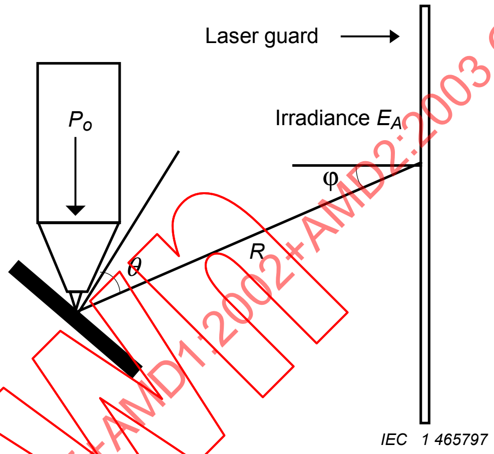

Figure B.1 – Calculation of diffuse reflections

B.2.2 Specular reflections

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

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

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

where ρ is the reflectivity of the workpiece surface.

CAUTION: Certain curved surfaces may increase the reflection hazard.

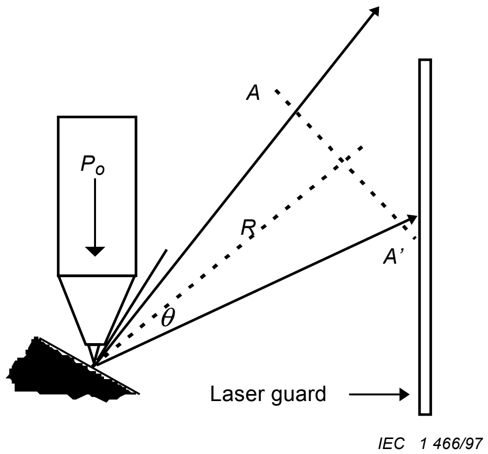

Figure B.2 – Calculation of specular reflections

B.3 Examples of assessment conditions

FELs should be assessed for the worst reasonably foreseeable combination(s) of available laser parameters, workpiece materials, geometry and processes likely to be encountered during normal operation (annex E of IEC 60825-1 provides a list of common fault conditions).

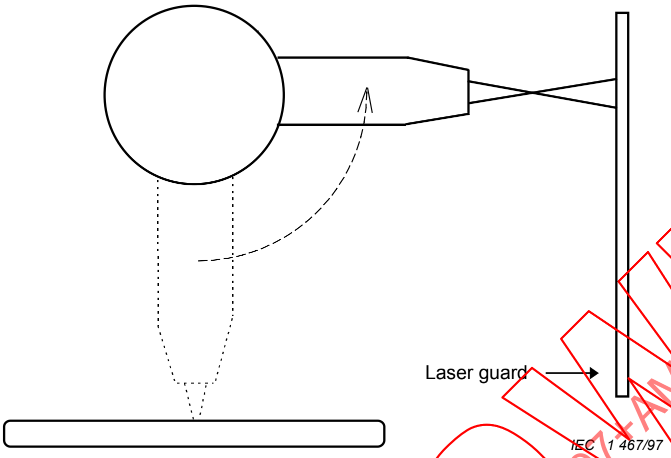

Figure B.3a – Software failure

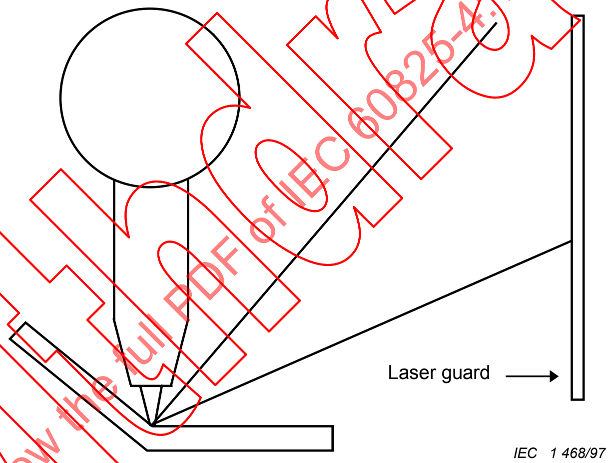

Figure B.3b – Workpiece bends or is inadequately clamped

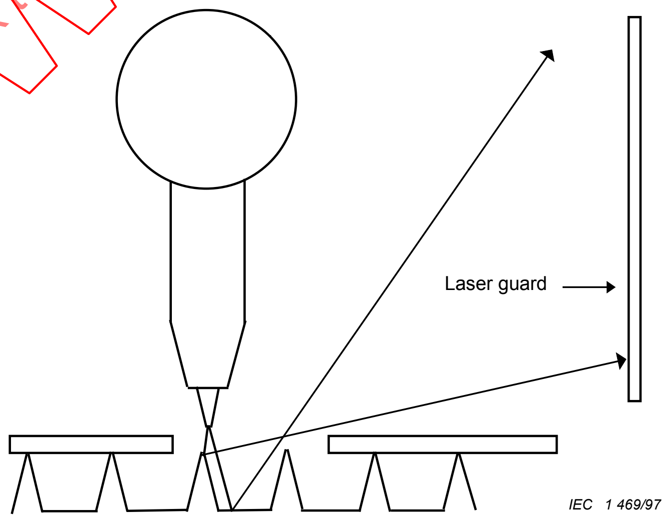

Figure B.3c – Workpiece missing

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

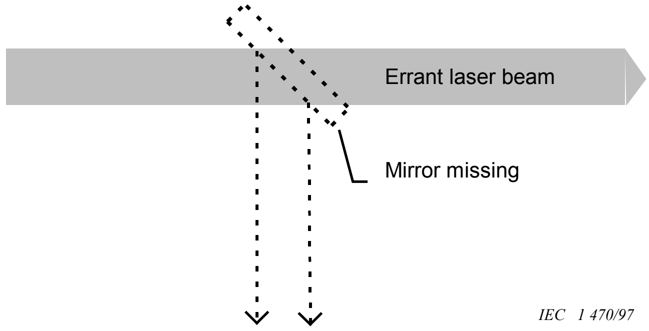

Figure B.4a – Laser is operated with turning mirror missing

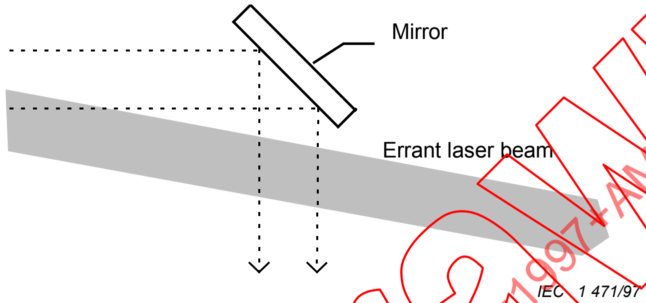

Figure B.4b – Beam displaced off mirror during alignment procedure

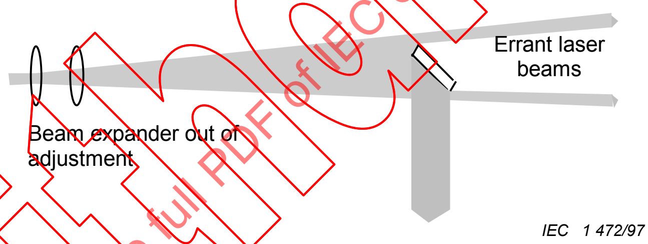

Figure B.4c – Beam expands beyond range of optics

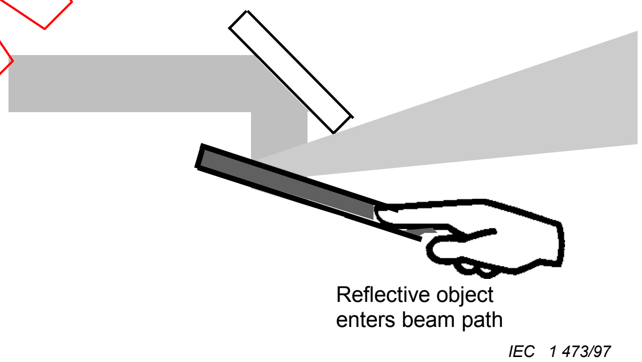

Figure B.4d – Reflective objects intercept laser beam

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

B.4 Exposure duration

B.4.1 Normal operation

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

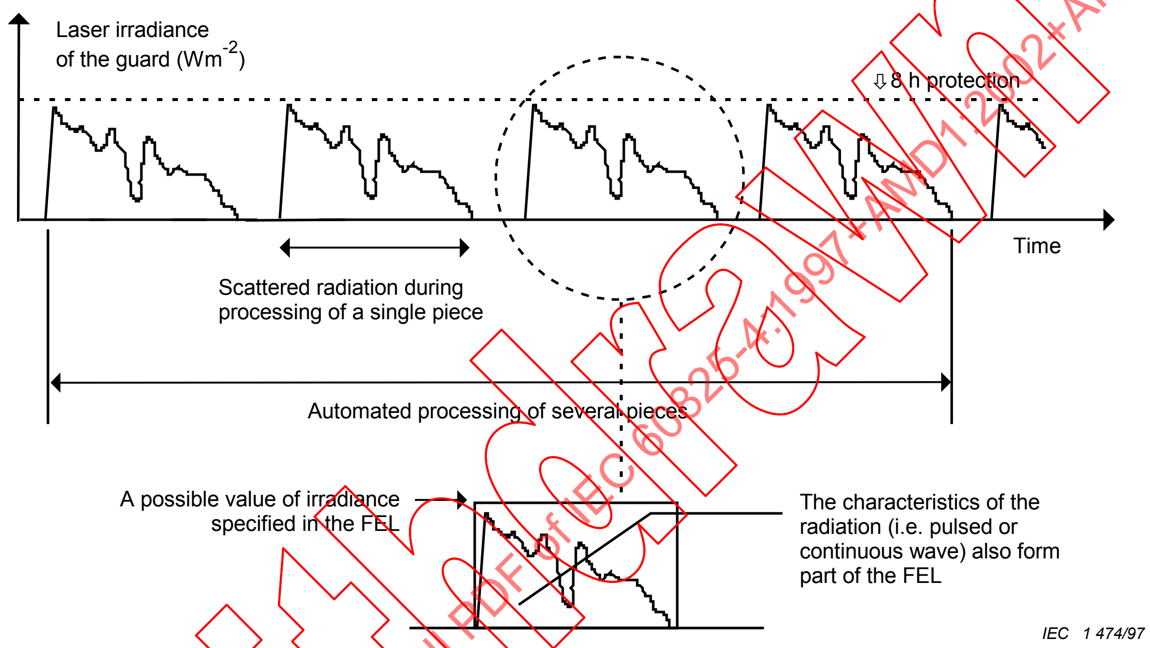

Figure B.5 – Illustration of laser guard exposure during repetitive machine operation

B.4.2 Fault Conditions

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

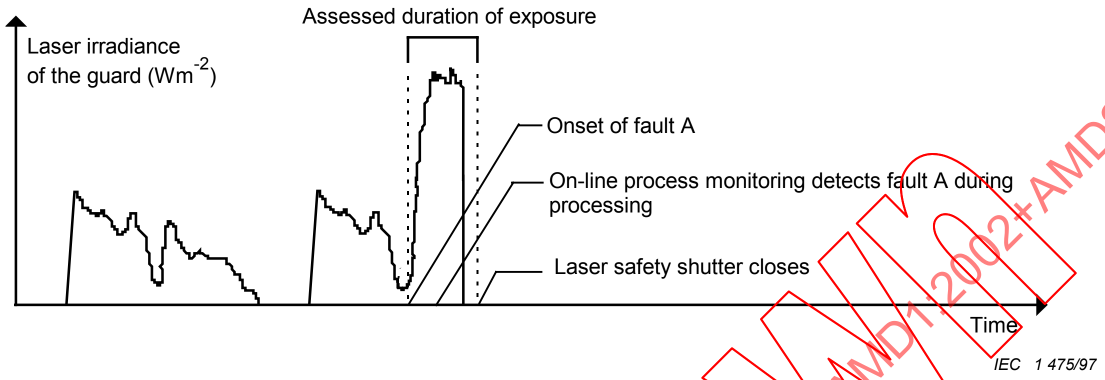

Figure B.6a – Shut-down with on-line machine safety monitoring

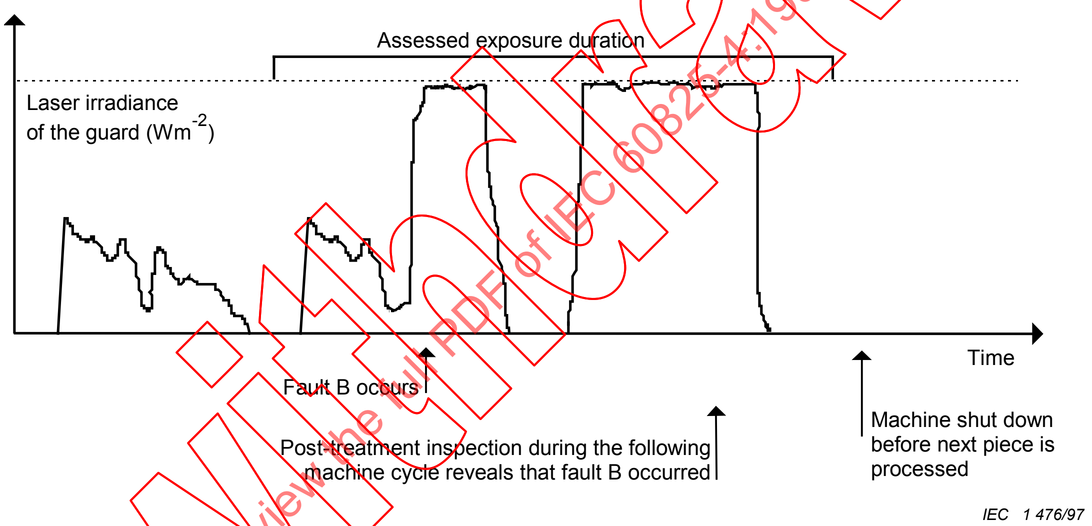

Figure B.6b – Shut-down with off-line machine safety monitoring

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

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

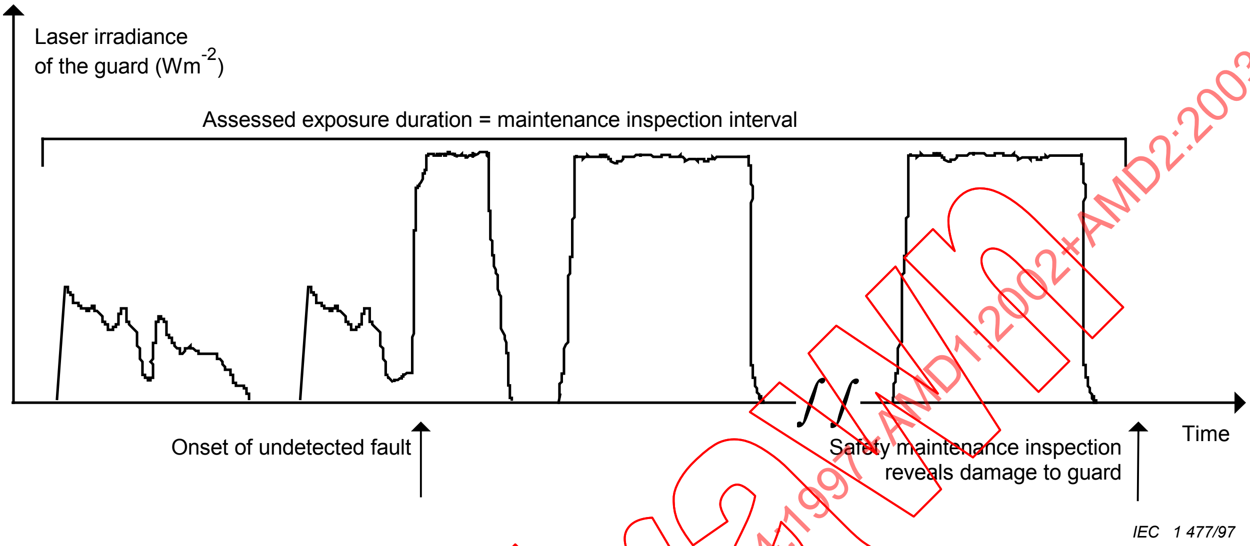

Figure B.7 – Assessed duration of exposure for a machine with no safety monitoring

B.4.3 Servicing operations

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

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

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

B.5 Reference document

prEN 1050: 1993, *Safety of machines – Risk assessment*

Annex C
(informative)

Elaboration of defined terms

C.1 Distinction between FEL and PEL

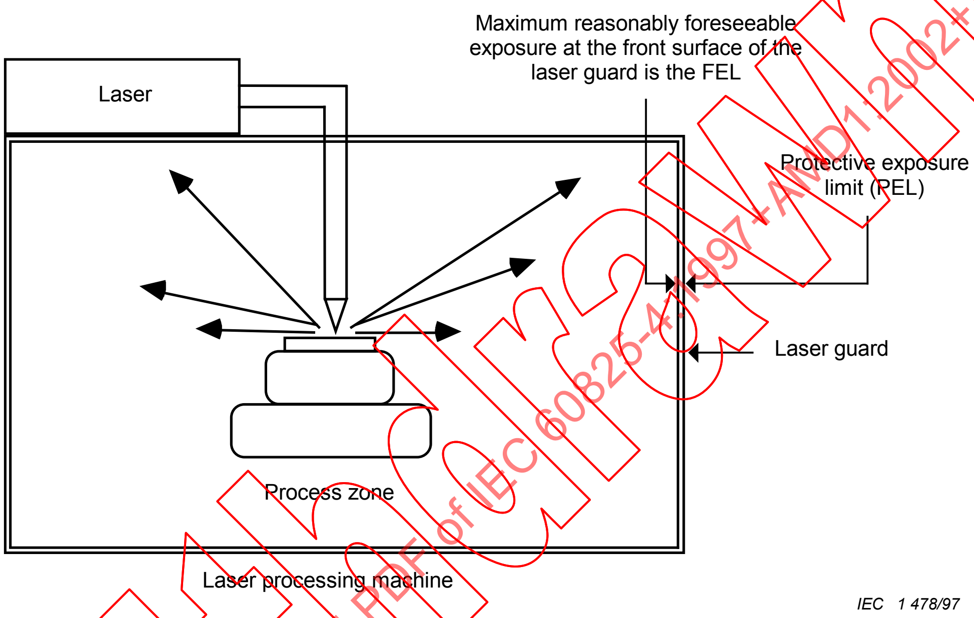

Figure C.1 – Illustration of guarding around a laser processing machine

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

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

C.2 Active guard parameters

An active guard has two essential components:

a) 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;

b) 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. 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.

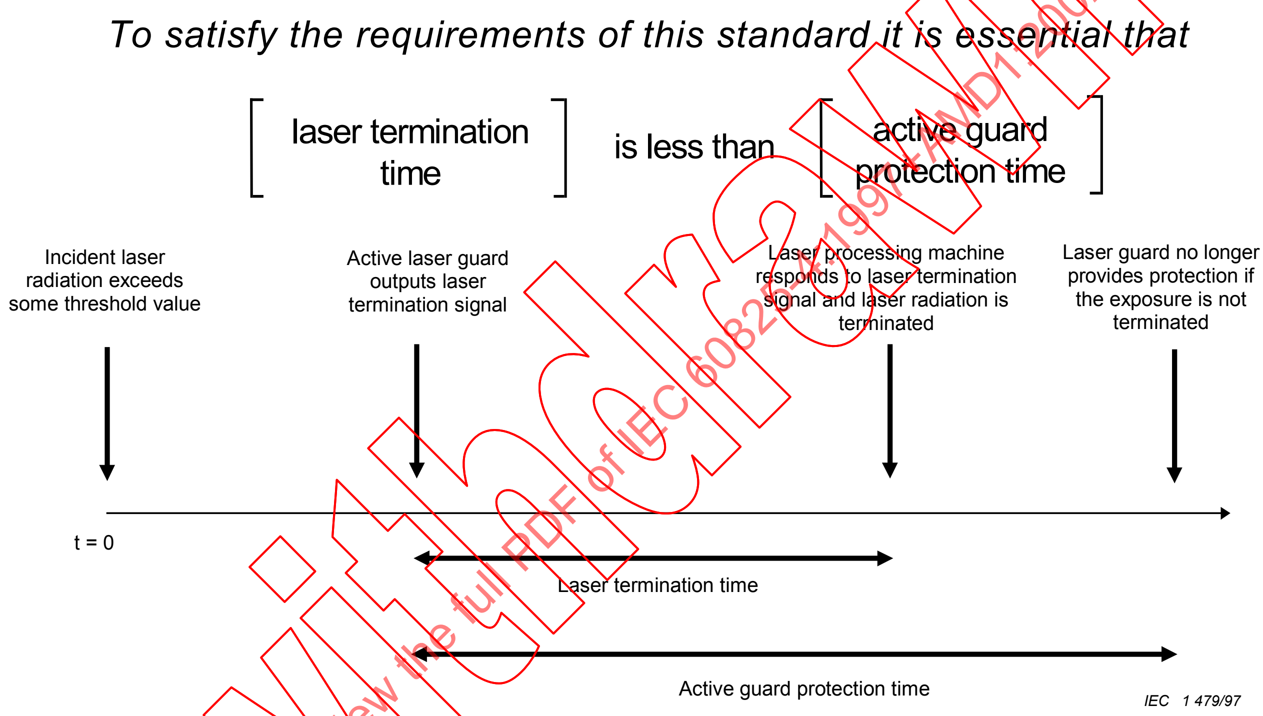

Figure C.2 – Illustration of active laser guard parameters

Annex D
(normative)

Proprietary laser guard testing

D.1 General

It should be noted that it is inappropriate to use higher power lasers to simulate low power laser parameters 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.

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 as a guide for laser guard comparison purposes.

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 limiting irradiance value, which indicates protection, decreases as the laser beam dimensions increase.

D.2 Test conditions

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 one surface of a sample of representative thickness and composition and of dimensions not less than 3 times the maximum beam dimension (1/e^2) encountered 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 %.

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

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 (±3° to avoid retro-reflections) to the laser beam with the beam axis centred on the sample at a distance ‘F1’ as shown in Figure D.1. The distance F1 past the focal point shall be not greater than 3 times the focal length (F) of the focusing lens.

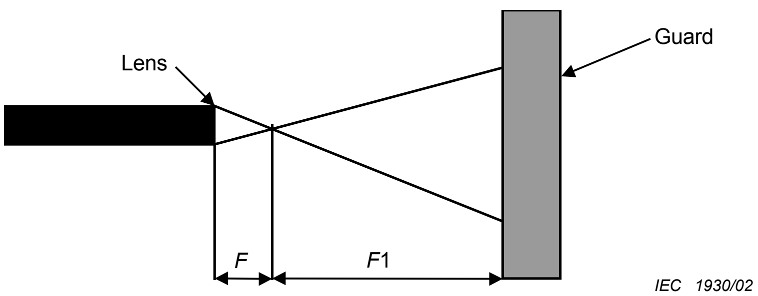

Figure D.1 – Simplified diagram of the test arrangement

For passive 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 dependant on the period of exposure set by the manufacturer of the proprietary guard.

NOTE Maintenance inspection intervals of proprietary laser guards should be specified by their manufacturer using classifications T1, T2 or T3 as defined in Table D.1.

Table D.1 – Laser guard classification

Test classification	Maintenance inspection interval s	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

For active guards two tests shall be satisfied:

a) 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. A reasonably foreseeable fault within the active guard system shall not lead to the loss of the safety function. The reasonably foreseeable fault within the guard element shall be detected at or before the next demand upon the safety function.

b) 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 protection time (as defined in 1.3.1).

D.3 Protective exposure limit (PEL)

The protective exposure limit (PEL) (as defined in 1.3.13) specified by the manufacturer shall be equal to the tested exposure limit, which satisfies the above conditions, multiplied by a correction factor of 0,7,

i.e. $$\text{PEL} = 0{,}7 \times \text{tested exposure limit}$$

Annex E
(informative)

Guidelines on the arrangement and installation of laser guards

E.1 Overview

This informative annex 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 the annex 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 this annex.

E.2 General

E.2.1 Introduction

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:

– the laser guard should be located at least 3 focal lengths away from the focal point of a focussing lens;

– 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 Clause 4.2.1 of IEC 60825-1 and encompasses the embedded laser and the entire process zone, such that there is no human access to hazardous radiation.

[1] Also published by the European Committee for Standardization as EN 12626.

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 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 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 UVB and UVC, protective clothing may be required.

E.2.8 Human intervention

Where machine operations require a 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 authorised 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

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 EN 1050.

E.3.2 General 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 the following.

E.3.2.1 Features of the laser process zone

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

E.3.2.2 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.3.2.3 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/ number of items), and the means and effectiveness of automatic process control intervention in the event of a fault condition becoming evident.

E.3.2.4 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.3.2.5 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.3.2.6 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.3.2.7 Clamping and fixturing

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

E.3.2.8 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.3.2.9 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 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 give rise to optical misalignment. Attention should 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.3.2.10 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.3.2.11 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.3.2.12 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.3.2.13 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

- Example

Laser processing unit mounted over a conveyor belt.

- Location

During normal production or maintenance, access is controlled and only accessible to authorised 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.

- 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.

- Possible solutions

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.

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 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

- Example

Flatbed cutting table in laser job-shop environment.

- Location

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

- Key issues

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

- Possible solutions

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.

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 unauthorised and untrained persons are prevented from exposure to any hazard that may cause harm.

E.4.3 Multi-axis processing machine

- Example

Automated robotic laser welder on an automobile line.

- 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 authorised persons and the area restricted and not open to other untrained personnel.

- Key issue

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

- Possible solutions

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.

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 IEC 60825-4 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

- Example

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

- 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 authorised 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).

- Key issue

Beam direction is under administrative control.