IEC TR 60825-3

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TECHNICAL REPORT

Safety of laser products –
Part 3: Guidance for laser displays and shows

colour inside

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Safety of laser products –
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INTERNATIONAL
ELECTROTECHNICAL
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SAFETY OF LASER PRODUCTS –

Part 3: Guidance for laser displays and shows

FOREWORD

IEC TR 60825-3 has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment. It is a Technical Report.

This third edition cancels and replaces the second edition published in 2008. This edition constitutes a technical revision.

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

a) updates and provides additional terms and definitions relating to laser displays and shows;

b) adds information on exposure hazards and biological effects;

c) updates and provides additional safety criteria from a technical perspective of equipment and installations;

d) updates and provides additional safety management guidance for designers, installers, operators and performers;

e) adds guidance on identifying and managing laser display risk, including laser effect exposure risk categories to aid management;

f) adds guidance on the management of incidents and accidents;

g) adds guidance on exposure assessment, highlighting evaluation and measurement difficulties, and providing guidance on undertaking measurements.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
76/662/DTR	76/692/RVDTR

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 Technical Report is English.

A list of all parts in the IEC 60825 series, published under the general title *Safety of laser products*, can be found on the IEC website.

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 publication 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

Laser products are used to create visual lighting effects for the purposes of entertainment. IEC 60825-1 considers the hazard classification and engineering requirements of laser products, while IEC TR 60825-14 provides general user guidance for the safe use of laser products.

The laser power needed to produce visually effective theatrical or artistic displays in large spaces such as theatres, arenas, or architectural sites is great enough to pose a severe accidental exposure hazard, even when personal exposure is very brief. For this reason, IEC TR 60825-14 states that only laser products that are Class 1, Class 2 or visible-beam Class 3R should be used for demonstration, display or entertainment purposes in unsupervised areas. Only under carefully controlled conditions and under the control of a trained experienced operator can laser products of higher classes be used for visual entertainment.

This document expands upon the principles considered in IEC TR 60825-14, providing specific technical guidance appropriate for the safe use of laser products used for the purposes of visual entertainment.

SAFETY OF LASER PRODUCTS –

Part 3: Guidance for laser displays and shows

1 Scope

This part of IEC 60825, which is a Technical Report, gives guidance on the planning and design, set-up and conduct of laser displays and shows that make use of high power lasers emitting output between 380 nm and 780 nm.

This document does not include the display or demonstration of scientific, medical or industrial laser products that can be used in an exhibition environment for example. However, several of the principles in this document could be relevant. This document provides recommendations for safety for those laser displays or demonstrations that are shows, artistic displays, advertising or light sculptures, or museum pieces used to demonstrate optical principles, etc.

Laser products available for use in a domestic environment or for use by people who cannot be expected to have received a suitable level of training are typically limited to Class 1, Class 2 or visible-beam Class 3R. Therefore, the use of such equipment is outside the scope of this document.

Image projectors that were assigned a Risk Group in accordance with IEC 62471-5 [1][1] or laser illuminated luminaires employing lamps meeting the criteria of 4.4 of IEC 60825-1:2014, are not within the scope of this document.

This document contains safety criteria for the protection of the public or persons in the vicinity of laser displays in the course of their employment.

This document is intended to be used by those who:

- design, manufacture, assemble, install or operate laser products that are Class 4, Class 3B, or non-visible beam Class 3R for display and entertainment purposes;
- operate arenas, theatres, music festivals, TV studios, planetaria, discotheques or other places where such laser products are installed and operated; or
- are responsible for reviewing the safety of such equipment, installations or displays.

This document is a code of practice for the design, installation, operation and evaluation of the safety of laser light shows and displays, and the equipment employed in their production. This document is also intended for persons who modify laser display installations or equipment.

In some countries, there are specific requirements, such as government permissions or notifications of shows, or prohibitions, such as against laser scanning of spectators.

1 Numbers in square brackets refer to the Bibliography.

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, *Safety of laser products – Part 1: Equipment classification and requirements*

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:

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

3.1
aversion response
reflex avoidance action (closing the eyes and turning away) when a person is suddenly exposed to a bright light source

Note 1 to entry: Through this action the duration of an accidental exposure to a visible beam is normally considered to be 0,25 s. However, alcohol or narcotic substances can have a detrimental effect on the aversion response, and even without such influences spectators can be inclined to override this response to continue viewing the performance.

3.2
Amsler grid
visual tool used to detect vision problems resulting from damage to the macula, the part of the eye used to detect central vision detail

3.3
ancillary personnel
backstage workers, ushers, security guards, technicians, food and beverage suppliers, etc., who are working at the venue or facility at which a laser display or show is being set up or presented, but who are not directly involved with the laser display or show

Note 1 to entry: Ancillary personnel can have access to areas from which spectators are excluded.

3.4
aperture
opening in the protective housing of a laser product through which laser radiation is emitted, thereby allowing human access to such radiation

Note 1 to entry: The aperture is of limited size so that only the intended laser effect can emit from laser projector.

3.5
audience illumination
laser lighting effect that is intentionally accessible, allowing direct illumination of the area occupied by spectators

Note 1 to entry: Common techniques used to produce this type of effect include:

- direct scanning of the laser beam, using electromechanical devices, such as galvanometers, to deflect the beam position, typically, in a dynamic fashion;
- diffraction effect (3.12) using diffractive optic elements;
- high inertia scanning effects, such as rotating polygon mirror and mirror ball beam deflection;
- solid-state beam deflection techniques, using devices such as acousto-optic modulators and microelectromechanical systems (MEMS).

Note 2 to entry: The varying characteristics associated with each different effect type influence the degree of hazard present and how it can be managed. Factors include differing maximum peak irradiance, exposure duration potential, time available for effective scan-fail detection and mitigation.

3.6
barrier
device to separate spectators from zones where potentially hazardous laser radiation exists

Note 1 to entry: It is important that barriers are robust and not capable of being readily displaced or traversed by spectators.

Note 2 to entry: A barrier can be a wall, a fence, stage front, etc.

Note 3 to entry: Less substantial barriers such as stanchions or ropes can be considered to be adequate barriers if the entire protected area is visible to and monitored by the laser operator or other safety and security personnel during the laser display.

3.7
bounce mirror
mirror located remotely from the laser projector used to target a static beam

Note 1 to entry: Bounce mirrors are often used in multiples to create the appearance of multiple networks of beams.

3.8
control signal
means by which the laser projector is controlled by the laser operator or a pre-programmed control system

Note 1 to entry: The resilience of the control signal to interference from other of sources within the environment is important. For this reason, the use of wireless control signals is discouraged.

3.9
controlled location
area inaccessible except to authorized, trained persons that have received sufficient training or instruction about laser safety

Note 1 to entry: Controlled locations typically include the performer zone, but can also encompass restricted areas where laser beams are accessible. They also include restricted areas in which ancillary personnel can be present or to which ancillary personnel have access.

3.10
designer
person who determines the visual effects to be produced, the planning of the projections, and the locations of the equipment to be used

Note 1 to entry: The designer can, in addition, act as installer or operator and be considered to be a manufacturer (3.27) or supplier.

3.11
display safety record
DSR
written record of safety information relevant to a specific laser display or show

3.12
diffraction effect
type of laser effect produced by the interaction of a laser beam with a diffractive optical element (DOE) or diffraction grating

Note 1 to entry: The laser beam interaction causes the original beam to split and form a geometric pattern, such as a grid or line of beams. The appearance of the emergent pattern is predominantly determined by the characteristics of the DOE. The substrate containing the DOE is usually rotated during use to create the appearance of movement.

Note 2 to entry: Diffraction effects can be produced either by using a reflective substrate which behaves like a mirror, with pattern being formed as a reflection, or by using a transmissive substrate, where the beam passes through the DOE and the pattern is formed at the beam exit. Reflective diffraction effects are often used in similar fashion to bounce mirrors. Transmissive laser effects are typically created within the laser projector itself, with the DOE being moved into the path of a stationary laser beam or scanning output.

Note 3 to entry: Diffraction effects normally contain a zero order (3.46) beam.

3.13
effective pulse duration
time taken for a moving beam to traverse the 7 mm limiting aperture of the eye

Note 1 to entry: Often used for evaluating the exposure created by a scan pattern or moving effect, where in most instances the exposure experienced by a person is independent of the, often CW, laser source output characteristics.

Note 2 to entry: This duration can be estimated by considering the leading and trailing edges of a top-hat scanning beam profile passing over the pupil.

3.14
emergency stop control
e-stop
reliable method of terminating the output of a laser projector system

Note 1 to entry: It is important the emergency stop control functions independently of the laser system's control signal, which can become unstable in the case of a fault occurring. This is particularly important as common lighting and laser effect control protocols generally have no or little fault tolerance.

3.15
engineering control
mechanical or electrical safety measure intended to continuously protect people from exposure to a hazard, usually characterized by being in addition to the system and not relying on specific human action to be effective

Note 1 to entry: Common examples include key operated controls, warning indicators, and physical masking.

3.16
errant laser effect
laser beam that deviates from a defined or intended beam path

Note 1 to entry: Such beams include unwanted reflections in the projection area, or movement of the laser projector or remote optical target causing laser beams to appear outside of the intended projection area.

3.17
inaccessible location
area that can be accessed only using specialized equipment, additional equipment, or both

Note 1 to entry: Access equipment typically includes mobile lifts, ladders, ropes, scaffolding, etc.

3.18
intentionally accessible effect
laser effect category that by design and implementation permits beams to be readily accessible to persons

Note 1 to entry: An example of this category of effect is audience illumination, but could equally apply to others, such as performers and ancillary personnel illumination. In each instance it is important that any exposure is not in excess of the applicable MPE.

3.19
installer
person who places the equipment in the designated locations and participates in the adjustment and alignment to produce the desired effects

Note 1 to entry: An installer may also be a manufacturer (3.27) or supplier if the installation activities result in modification of the display laser product effects.

3.20
laser classification
indication of the potential risk of harm of a laser, where the higher the class number indicates a greater hazard from exposure to the laser beam emitted by the product

Note 1 to entry: IEC 60825-1 defines eight distinct laser hazard classes that identify the general risk posed by a laser product and mandates the required safety features that the laser product is to have based on its accessible laser radiation.

Note 2 to entry: The majority of laser projectors used to create laser effects are Class 3B and Class 4 laser products that emit beam(s) posing a risk to eyes and skin, and can act as a source of fire ignition.

3.21
laser display or show
activity where at least one laser beam is projected onto a surface or made visible in the air, for purposes such as entertainment or art, and usually intended to be viewed by a non-specialist audience

Note 1 to entry: This definition includes demonstrations, such as in museums or educational establishments, and laser shows such as in planetariums, nightclubs, concert and entertainment venues, art installations and advertising projections.

3.22
laser effect
all electromagnetic radiation emitted by a laser product between 380 nm and 780 nm which is produced as a result of controlled stimulated emission

Note 1 to entry: A laser effect can appear stationary or moving using optical components to manipulate the characteristics of the laser beam.

3.23
laser effect category
identification of the laser effect application based on the intended accessibility to the laser beam(s)

Note 1 to entry: Laser effects are considered to belong to one of three categories based on the potential for direct exposure, which helps to identify the specific types of controls necessary to safely manage use of the laser effect.

3.24
laser projector
laser used, alone or with beam-manipulating components, to produce laser displays or show effects

Note 1 to entry: Laser projectors are considered laser products subject to the applicable provisions of IEC 60825-1, within the scope of this document.

3.25
laser protection adviser
LPA
person who is usually independent of the laser installation and its day-to-day operation, but who is suitably qualified in understanding laser hazard prevention strategies, is able to understand and assess safety matters in relation to laser display installations, evaluate and quantify exposure levels, and is familiar with the appropriate legal responsibilities and requirements

3.26
laser safety officer
LSO
person who is knowledgeable in the evaluation and control of laser hazards and has responsibility for oversight of the control of laser hazards

Note 1 to entry: The role of the laser safety officer can vary widely, depending on the safety management needs of the organization in which he or she is employed. It is often not necessary for the laser safety officer to be able to perform quantitative hazard analyses.

Note 2 to entry: Organizations using Class 3B and Class 4 laser equipment normally appoint an internal laser safety officer to take administrative responsibility on behalf of the employer for overseeing laser safety.

Note 3 to entry: The duties of the laser safety officer are usually documented and are those necessary to ensure the continuing safe use of lasers within the organization concerned. They are likely to include as a minimum:

a) being aware of and, if appropriate, maintaining records of, all potentially-hazardous laser products (including the classifications, specifications, and purposes of the laser products; the locations of the laser products; and any special requirements or restrictions relating to their uses);

b) responsibility for monitoring compliance with the organization's procedures for ensuring safe laser use, for maintaining appropriate written records, and for taking immediate and appropriate action in respect of any non-compliance or apparent inadequacy in such procedures.

3.27
manufacturer
person (or persons) who constructs, assembles or produces one or more laser projectors, or the displays or shows (physical set-up of equipment) which use laser projectors

Note 1 to entry: This applies whether or not the manufacture is done for profit.

Note 2 to entry: The equipment used to produce a laser display or show is considered to be a laser product.

3.28
mask
baffle
physical mask
physical mask able to stop laser beams from travelling in unwanted directions

Note 1 to entry: The mask is generally a sheet or panel made of durable material able to withstand, without penetration, the maximum anticipated level of laser radiation. It is important the mask does not slip or move relative to the impinging laser beam.

Note 2 to entry: Beams controlled by electronics or computers will often employ "software masks" so the beam is prevented from emitting, or operating at maximum output, in defined areas within the potential projection area. If software masks are used then it is important that full consideration of the failure modes of the scanning system and the consequences of failure be considered. In some situations, more formal assessments, such as described in the IEC 61508 series [2], will be needed.

Note 3 to entry: It is important the performance of masks, whether physical or software, be evaluated under reasonably foreseeable single fault conditions.

3.29
modifier
person who changes the performance, layout, or effects of a laser display or show, or who makes changes in the components of the system that impact the safety characteristics

Note 1 to entry: A modifier is also considered to have the same responsibilities as a manufacturer (3.27), supplier or designer (3.10).

3.30
non-accessible effect
laser effect category that by design and implementation renders no beams as being accessible to any person

Note 1 to entry: The laser projector and beam trajectory are located in an inaccessible location, normally supported by the use of engineering controls to prevent errant laser effects.

3.31
operator
person who has direct operational control of the laser or projection system(s)

Note 1 to entry: It is important operators be trained on the hazards involved with the lasers being used and are expected to comply with the safety instructions that are provided by the manufacturer (3.27). An operator can also be designated as the laser safety officer for the laser display or show.

3.32
performer
person who entertains the public during a show

Note 1 to entry: Performers can be dancers, singers or musicians, etc.

Note 2 to entry: Performers are expected to have been instructed on the hazards involved with the lasers being used and can often be reasonably expected to comply with the safety instructions that are provided.

3.33
performer zone
area in which only performers may be present and within which laser radiation may exceed the spectator MPE

Note 1 to entry: The performer zone is usually a controlled location situated on a stage.

3.34
potentially accessible effect
laser effect that by implementation is not designed to be intentionally accessible, but within the designated controlled location beams in excess of the applicable MPE could be accessed if there are not sufficient controls in place, or controls are ignored by persons present within the controlled location

3.35
projection area
area in which the laser beam or effect is designed to be present during normal intended operation of the laser projector

Note 1 to entry: The projection area includes the space the beam or beams travel through, and the surfaces where they terminate.

3.36
responsible person
person, working in the field, who takes charge of the laser installation, the operation of the laser effects or both, and in doing so is responsible for ensuring such work is carried out in a way that minimizes exposure risk, and does not deviate from the parameters agreed with the laser safety officer, the laser protection adviser or both

Note 1 to entry: It is important the responsible person have received basic training and instruction on how to carry out their task in a safe manner, be able to identify and avoid hazardous situations arising, and be able to terminate laser output where necessary to prevent harmful exposure.

Note 2 to entry: In some situations, the same responsible person can undertake the laser effect design, installation, and operation roles for the provision of the display. There are circumstances however where different persons need to adopt the role of the responsible person. For example, where a laser installation has been installed into a venue, and operation is handed over to the venue's technicians, different people adopt the role. There can be a hierarchy of responsible persons at an installation where, for example, a venue's safety manager adopts a senior role, ensuring that its technicians and operators are aware of and fulfil their obligations during laser effects operation.

3.37
restricted location
area that is inaccessible to spectators and general public but can be accessible to other observers or untrained personnel

Note 1 to entry: Employees of the venue, and ancillary personnel are likely to be considered untrained personnel.

3.38
scan pattern
effect produced when a laser beam is scanned, often using a pair of mirrors mounted on galvanometers

3.39
scan-fail safeguard
engineering feature of a laser projector that is intended to prevent access to laser effects in excess of the relevant MPE

Note 1 to entry: This feature is often incorporated into the scanning element of a laser projector to prevent the emission of a stationary beam, or beams that move too slowly. All scan-fail safeguards have a finite response time.

Note 2 to entry: Scan-fail safeguards vary in complexity. Rudimentary systems can prevent the output of a stationary beam, monitoring the derivative of the x- and y-axis galvanometer velocity feedback signals in a closed loop scanning system. More sophisticated systems monitor additional characteristics including the movement and repetition of the scan pattern, and sample the beam output, to actively limit the beam emitted from the laser projector where necessary.

Note 3 to entry: The presence of a scan-fail safeguard does not make application of the laser projector for audience illumination inherently safe. It is important the user fully understands the parameters and failure modes the scan-fail safeguard is able to act upon, and the implications of these characteristics. Safety of the resultant exposure is additionally dependent on other factors such as the laser beam characteristics – e.g. the radiant power, beam divergence – and proximity to the spectators viewing the display.

Note 4 to entry: It is critical the reliability of the scan-fail safeguard takes into consideration all possible failure modes of the scan-fail safeguard and correct operation be verified at regular intervals.

Note 5 to entry: In some situations, more formal assessments, as described in the IEC 61508 series [2], will be needed.

3.40
scan-fail safeguard response time
total time taken for a scan-fail safeguard to detect a fault, trigger a corrective action, and for the corrective action to become effective

Note 1 to entry: The scan-fail safeguard response time to correct a hazardous emission is inevitably longer than just the fault detection time alone. It is important to exercise caution when considering durations quoted by laser projector manufacturers (3.27), who typically state the fault detection time only.

3.41
spectator
person who is present at the laser display or show who, by location or proximity, could potentially be exposed to hazardous direct or reflected laser beams (in the absence of any safety features, or in a worst-case situation) and who is the intended audience for the laser-created effects

Note 1 to entry: This does not include the laser display operator and their staff, or performers, but could include bystanders and others that are not part of the performance and are untrained.

Note 2 to entry: Spectators can neither be expected to have been briefed on the safety procedures regarding the lasers in use, nor be expected to comply with safety instructions.

3.42
spectator MPE
maximum level of ambient laser radiation that may exist in a spectator zone

3.43
spectator zone
area in which spectators may be present and within which laser radiation is restricted to the spectator MPE

Note 1 to entry: Such areas are considered to be an unrestricted location (3.44).

3.44
unrestricted location
area where the occupancy and activity of the occupants is not subject to control or supervision for the protection of laser related hazards

Note 1 to entry: Such areas typically include the spectator zone.

3.45
x-y gain control
effect size
control to set the maximum scanning extent of each axis in an x-y based laser projector system

Note 1 to entry: This is often implemented as a control at the laser projector that reduces the control signal to the scanner driver amplifiers, or a numeric value set as a limit in software.

3.46
zero order
0-order
<beam> occupying the position of the incident beam axis for a transmissive diffraction element, or the reflection from the incident beam for a reflective diffraction element

Note 1 to entry: Emergent beams from a diffraction effect form multiple “orders” in the pattern.

Note 2 to entry: The zero order beam normally comprises the most energy of the emergent orders from a diffraction effect.

Note 3 to entry: The emergent higher order beams rotate about the zero order beam, which remains stationary when the diffractive optical element is rotated.

Note 4 to entry: It is important that the zero order beam itself not be directed into accessible areas, as the beam remains stationary, even with the effect rotating. Additionally, if the diffracting medium degrades, or falls out of the beam path, it makes a solid beam accessible, presenting a risk to persons in the area where the beam terminates.

4 Exposure hazards and biological effects

4.1 Laser projector classification and hazards

Most laser displays use Class 3B or Class 4 laser products in open spaces to produce laser effects that can be seen by spectators. Beams emitted by Class 3B lasers are capable of causing an eye injury if direct exposure to the beam is, even briefly, allowed to occur. Beams emitted by Class 4 lasers present a risk of eye injury from both direct beam exposure and in some cases, viewing diffuse reflections. Class 4 lasers may also burn skin, and act as fire ignition source. The beams from lasers should not be directed at people unless extreme caution is exercised to ensure the safe exposure. Video projectors and cameras may be damaged through direct exposure.

NOTE The definitions for laser classifications and MPE are provided in IEC 60825-1 and IEC TR 60825-14.

4.2 Biological effects on the eye

Visible beam exposure at sub-injury (below MPE) level can lead to temporary effects such as flash blindness, which can interfere with a person's ability to complete a task. Exposure to a laser beam in excess of the MPE can result in one or a combination of three different injury types, which can affect certain parts of the eye. Figure 1 illustrates the different parts of the human eye.

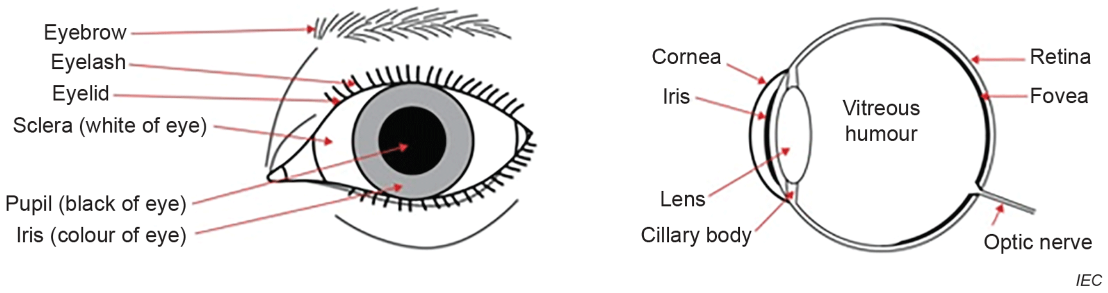


Figure 1 – Human eye

Thermal injury – caused by excessive heating of the absorbing tissue in the eye, which for visible light and near-infrared radiation exposure is the retina. No pain is experienced.

Photochemical injury – exposure to ultraviolet radiation and visible light between 400 nm and 600 nm. Injury occurs as a result of photochemical reaction occurring in the retina, lens or cornea, depending upon wavelength. In the visible part of the spectrum, exposure to blue light (wavelengths less than 500 nm), at levels lower than those that could cause a thermal injury, becomes the more dominant retinal hazard, through chronic and cumulative exposure.

Thermomechanical injury – occurs when the tissue is heated very rapidly, inducing rapid thermal expansion, leading to mechanical shockwaves.

Exposure to visible or near-infrared laser beams in excess of the MPE leads primarily to a risk of thermal injury on the retina, which can occur through even very brief exposure doses, such as those from a scanning laser effect. Additionally, photochemical injury risk becomes prevalent for longer duration and cumulative, sub-thermal MPE limit exposures to wavelengths below 500 nm. Thermomechanical injury can occur through exposure to high peak power q-switched pulsed lasers occasionally used for light shows.

During exposure to visible or near-infrared beams, the eye's retina has a much lower injury threshold than the skin. Even very brief exposure to a laser beam emitted from a Class 3B or Class 4 laser projector allows a risk of injury occurring within a person's natural aversion response. The output characteristics of most laser projectors used for laser display applications often remain hazardous for direct viewing up to distances several hundred metres from the source.

4.3 Biological effects on skin

Skin is at risk of suffering injuries, although the injury thresholds for harm to occur through exposure to visible and near-infrared beams are much greater than those that would otherwise cause harm to the eye's retina. Excess exposure to visible light and infrared radiation can lead to a sensation of pain, mild reddening or blistering of the skin, while ultraviolet radiation exposure risks similar effects to those associated with excess exposure to sunlight.

5 Zone limits and maximum permissible exposures (MPE) for laser effects

5.1 Compliance with maximum permissible exposure (MPE)

Under no circumstances should any person be exposed to laser beams in excess of the applicable eye or skin MPE. The maximum permissible level of laser beams to which a particular group of individuals can be exposed depends on the maximum exposure time assumed for that group. Local restrictions to the permitted MPE exist in several regions.

5.2 Spectator zone MPE

The exposure level of laser beams that may be present in the spectator zone should not exceed the MPE for intentional direct ocular exposure. The applicable MPE to be considered is determined using the data and methods described in IEC 60825-1 for all possible durations of exposure, t, including the maximum duration of the laser display or show, as appropriate (see below if the use of binoculars is likely). If the exposure level of laser beams is maintained as a result of scanning of the laser beam, the MPE for direct ocular exposure should also not be exceeded for the scan-fail safeguard response time (see 6.11 of IEC 60825-1:2014) or for the CW level of the laser beam (if there is no scan-fail safeguard).

Consideration should be given to any areas within the zone where the laser beam hazard can be greater, for example if beams are focused or static (such as at the end of scan patterns).

Use of viewing aids, such as binoculars, can potentially increase the hazard to spectators. At some venues, such as nightclubs, planetariums and corporate events, binocular use is not a problem. However, if binocular use is likely (e.g. at a large arena) and security is already used to prohibit cameras, recording devices, etc., it is recommended to additionally prohibit binocular use. If this is not possible (e.g. an open-air outdoor event), the spectator zone MPE should be multiplied by a factor of 0,02 to account for the increased hazard.

5.3 Performer zone (controlled location) MPE

The MPE for performers, operators or ancillary personnel who may be present in controlled locations such as the performer zone should be the MPE for direct ocular exposure, or the MPE for the skin (see IEC 60825-1) as appropriate. Performers should expect to have their actions choreographed, to be provided with protective eyewear and costuming if appropriate, and to be instructed in procedures to avoid exposure to laser beams in excess of the appropriate MPE. The maximum duration of any foreseeable or expected exposure should be considered. In some cases, performers may directly control laser safety features. For example, a performer steps on a switch to indicate he or she is in a safe location before beams can be emitted into the performance area. Any such control measures need to be carefully designed both for normal conditions, and for cases when a performer is off their mark or facing the wrong way (e.g. towards the laser) during a cue.

5.4 At-risk ancillary personnel MPE

Planning and implementation of the laser display installation and operation should ensure that the risk of laser beam exposure to any person outside of controlled locations such as the performer zone is not in excess of the spectator MPE. In circumstances where there is a possibility of a higher exposure potential occurring (such as during laser effect positioning and alignment), it is recommended to temporarily extend the controlled location and its associated precautions to include where the exposure risk may be present. Where extending the controlled area is not practicable, ancillary personnel that may be at risk from exposure should be identified and briefed about the exposure hazard. Care should then be taken to limit exposure from any accessible beams to the MPE for direct ocular exposure (see IEC 60825-1). This MPE anticipates that ancillary personnel are likely to be in locations other than the spectator zones, their movements are unlikely to be controlled, and they are unlikely to be provided with protective eyewear. However, they should be instructed to avoid looking directly into any incident beams, scanners or mirrors. For this reason, exposure durations up to 0,25 s should be considered for accidental exposure to visible laser beams. Where exposure to invisible laser beam radiation is possible, the accidental exposure duration should be evaluated in accordance with IEC 60825-1.

Table 1 – Summary of MPE selection criteria

Location or personnel	Accessible emissions in normal operation	Accessible emissions under reasonably foreseeable fault conditions
Spectator zone	MPE for direct ocular exposure	MPE for the response time of a scan-fail safeguard or other emission termination control
Performer zone	MPE for direct ocular exposure for accidental exposure (0,25 s for visible effects) assuming training in avoidance of ocular exposure. If ocular exposure is prevented, the skin MPE may be used.	MPE for direct ocular exposure for accidental exposure (0,25 s for visible effects) assuming training in avoidance of ocular exposure
At-risk ancillary personnel	MPE for direct ocular exposure for accidental exposure (0,25 s for visible effects) assuming training in avoidance of ocular exposure	
NOTE If exposure to invisible laser beam radiation is possible, consider evaluation of the accidental exposure duration in accordance with IEC 60825-1.		

6 Safety criteria for equipment and installations

6.1 The requirements of IEC 60825-1 are applicable to laser projection equipment.

6.2 Laser apertures should be masked using a material sufficiently robust to withstand direct exposure to laser beams for extended periods of time. The mask should be positioned to confine the projections to the intended directions and to prevent errant laser effect. Software masks, meaning a computer-programmed means to prevent beams in unintended directions, may be used when physical masks are not practicable, but consideration should be given to failure modes, and when used to restrict exposure in the spectator zone, safety critical software should be used. Standard laser projector scanner x-y gain controls, whether implemented in software or an analogue or digital potentiometer at the projector, are not effective masks. The effectiveness of any mask should be verified to ensure it prevents any output beyond the intended projection area.

6.3 Targets and bounce mirrors should be appropriately masked to prevent misdirection of a laser beam in the event that the laser becomes misaligned with the target.

6.4 Laser projectors, bounce mirrors and targets should be rigidly mounted to prevent movement due to vibration, jarring or the wind. Appropriate consideration should be given to the duration of the installation, human activity or through traffic, and the type of venue.

6.5 Scanning devices and their control systems should be designed to prevent (during normal operation and under any reasonably foreseeable fault condition) exposures greater than those permitted in the respective zones identified in Table 1.

6.6 A laser projector or its supporting structure intended to incorporate physical movement (such as a moving head laser, or moving truss) should employ a robust means of limiting movement to areas that would cause the relevant MPE to be exceeded. If such a system is not present, any exposure assessment should use the shortest separation distance to the source, to limit exposure, even if this is not the intended laser display separation distance.

NOTE 1 Reliance upon unidirectional control signals or communications protocols to set position parameters is not considered a robust means of setting the output direction of the laser projector for a safety critical application.

NOTE 2 Limiting the movement of the laser projector could be achieved using adjustable mechanical stops to restrict movement. An electronic position registration and monitoring system could be employed if it offers sufficient reliability. In some situations, more formal assessments, such as described in the IEC 61508 series [2], will be needed.

6.7 The control signal link between the control position and the laser projector should be of a robust design and offer high resilience to interference that can be reasonably be expected in the environment in which the laser display is taking place. A break or error in the control link should automatically terminate the laser projector's output.

6.8 Each laser installation should be provided with one or more clearly identifiable and easily operated emergency stop controls which immediately terminate the laser beams when required. The emergency stop control should be of a fail-safe design.

NOTE Using a keypress such as "esc", which is normally the designated command for a blackout condition on a computer-controlled laser effects system, or the use of a "black out" channel on a DMX lighting control system, is not considered a reliable emergency stop control.

6.9 Control signal, power and emergency shut-off cables should all be in good physical condition and use connectors that have a locking action.

6.10 If the laser display or show is under the continuous control of an operator who can immediately terminate laser beams in the event of a problem, a minimum separation distance of 3 m in height and 2,5 m laterally should be maintained between beams that exceed the spectator MPE and any surface upon which spectators can reasonably be expected to stand. This condition is shown in Figure 2 and Figure 3.

NOTE If the dimensions of the room are inadequate to provide these minimum separation distances, it is important a detailed assessment of the risk of exposure be carried out.

Dimensions in metres

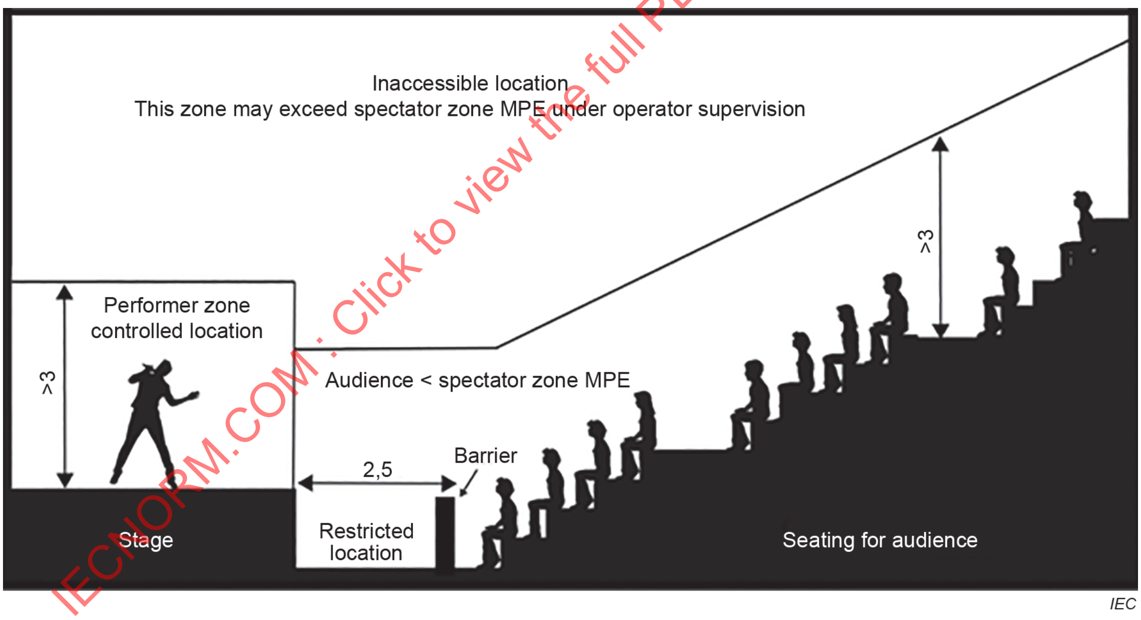
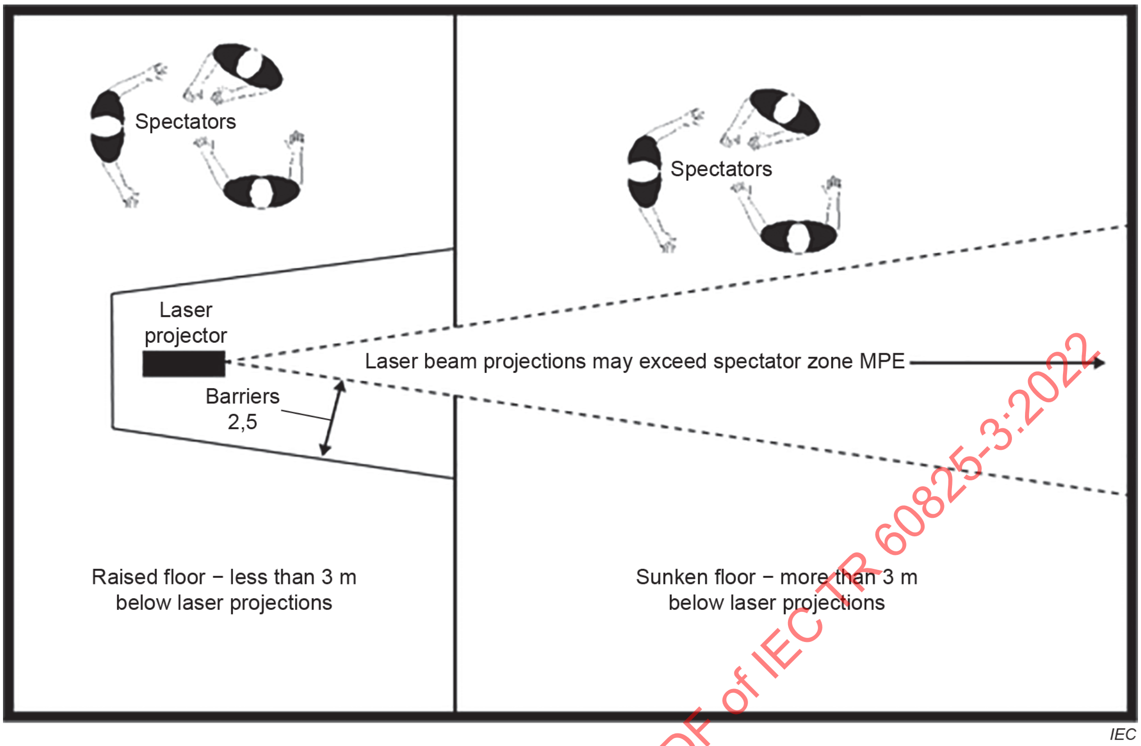


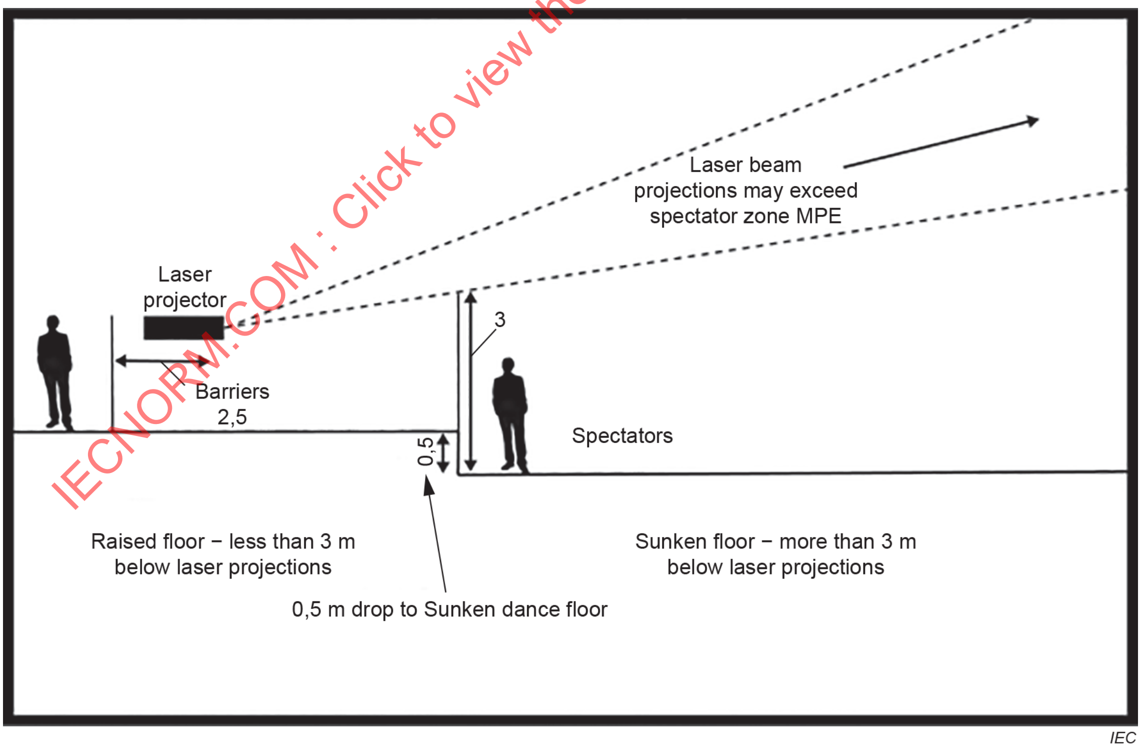
Figure 2 – Audience/spectator separation auditorium scenario with operator in control

Dimensions in metres



a) **Plan view**

Dimensions in metres



b) **Side elevation**

Figure 3 – Audience/spectator separation nightclub scenario with operator in control

6.11 If a projection area terminates onto a balcony or near a window, where spectators can view the laser effect, and the exposure level at the termination point is likely to be in excess of the spectator MPE, the beams should terminate no higher than the floor level of the balcony if it has an opaque solid barrier. This condition is shown in Figure 4.

NOTE 1 When a laser effect is directed to terminate in such close proximity to spectators, it is important a risk assessment considers the exposure level at the termination point, and the likelihood of any small movement of the laser projector, and the consequences it could have on inadvertently moving the projection area away from the intended termination area. Laser projectors not secured to solid structures are more susceptible to movement, through sway, and additionally can be influenced by the mechanical movement of other lighting fixtures that share the same lighting truss.

NOTE 2 The effectiveness of the mask used to prevent any errant laser effect exposure that could result in the failure of the scanning system or the display content needs to be tested and considered.

Dimensions in metres

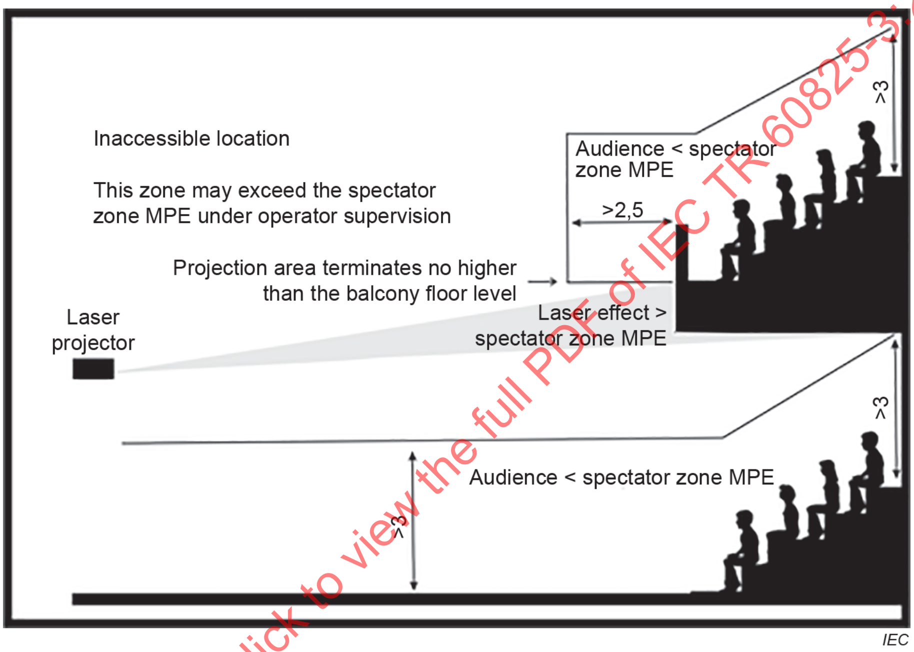


Figure 4 – Audience/spectator separation near a balcony with operator in control

6.12 If the laser display or show is not under the continuous control of an operator who can immediately terminate laser beams in the event of a problem, a minimum separation distance of 3 m in height and 2,5 m laterally should be maintained between beams that exceed the spectator MPE exceeded by more than a factor of 5 in the space between 3 m and 6 m above any surface upon which spectators can reasonably be expected to stand. This condition is shown in Figure 5.

Dimensions in metres

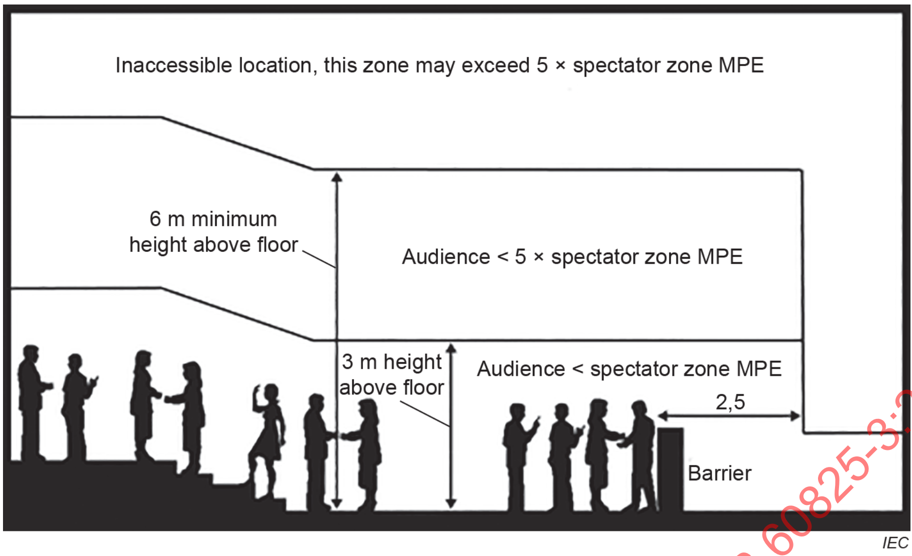


Figure 5 – Audience/spectator separation from unattended beams

7 Responsibilities of designers, installers, operators and performers

7.1 Training

7.1.1 Designers, installers, modifiers and operators should have received sufficient training in laser safety to be able to accurately assure that the MPE is not exceeded in spectator occupied areas and that the required separations are maintained between spectators and projections that exceed the MPE. Designers should also be trained to be familiar with the requirements of IEC 60825-1 and IEC TR 60825-14 regarding the security of locations in which laser beam exposure levels exceed the MPE, and to provide guidance to installers regarding the posting or placement of necessary warning signs.

7.1.2 Installers, performers and ancillary personnel should be instructed in procedures, as appropriate, to avoid hazardous exposure in areas in which laser beam exposure levels exceed the MPE and in the proper use of safety equipment.

NOTE It is important the degree to which a person is trained is sufficient to allow them to carry out their tasks in relation to, or in the vicinity of, the laser display installation, recognizing what could be hazardous acts or conditions, and taking appropriate action as necessary.

7.2 Planning by designers, installers and operators

7.2.1 Laser displays and shows should always be pre-planned and not improvised on the day of the event. The purpose of planning is to allow a safety assessment of any proposed display to be carried out in sufficient time for the necessary safety provisions to be made. The design of laser displays and shows should be accomplished as early as possible.

7.2.2 Plan and elevation drawings or sketches should be prepared showing locations of projectors, laser beams, mirrors and targets, the audience, performers and pertinent architectural features. The drawings should be checked to confirm that required separation distances are met and that spectator exposures will not exceed the applicable MPE. Contingency plans should be prepared to assure that equipment or projections do not obstruct or interfere with emergency exit routes during possible emergency conditions, e.g. fire. Plans should also consider the environmental effects of rain, wind, etc. on targets, mirrors, etc.

7.2.3 When planning the location of laser projectors, consideration should be given to minimizing the chances of accidental exposure to performers and ancillary personnel at performance time. For example, it is preferable to place a laser projector above head height on stage, removing the need for a higher-risk administrative control, of instructing persons to keep clear of the area, had the laser been mounted at chest or stage height, and the need to enforce and monitor a laser controlled area.

7.2.4 Organizational arrangements should be considered and documented to confirm details of staff, chains of accountability, and contact details. Any time when laser beams are emitted there should be an identified responsible person in control of the laser effects, who is able to recognize and prevent hazardous situations from occurring, and terminate laser effects as necessary.

7.2.5 Planning for how each phase of the project will be implemented and managed should take place at an early stage. Consideration should be given to the risks that can be present at each phase, with an appreciation that the nature of risks is likely to vary over the project lifecycle. A risk assessment should be carried out that considers who can be affected by the installation and use of the laser effect, together with any site-specific factors. The key findings and decided control measures, (precautions) should be documented. When planning the implementation phases of the display, planning typically includes the installation, alignment, laser effects programming and testing, the performance, and dismantling. On completion of a project it is beneficial as part of the safety management process to record key actions that worked well, and identify any issues that could benefit from improvement, so that these can be considered for future projects.

7.2.6 For any laser effects that are not intended to be accessible, planning should consider how to prevent any errant exposure and maintain separation from the laser effect.

7.2.7 Any laser effects that are not intended to cause exposure, but are potentially accessible, should be clearly identified, and planning should include how to prevent accidental exposure.

7.2.8 The exposure caused by laser effects intended to create either audience illumination or performer exposure should be evaluated and controlled to ensure the applicable maximum permissible exposure (MPE) is not exceeded. Planning should include provision and time for testing the exposure levels, and consider the effectiveness of any engineering control intended to limit exposure.

7.2.9 Emergency procedures should be clearly thought out, documented, and communicated to the appropriate people identified during the planning phase of the project. This should include clear instruction on what constitutes an emergency, and what action should be taken following an incident. In the case of any emergency, the laser effects should be stopped. In the case of a suspected eye injury through exposure to laser beams, unless an injury is obvious, in which case the casualty should be taken to the nearest accident and emergency hospital, it is usual to conduct a reading test and Amsler grid visual acuity test, to test macula function. If there is concern that it is possible an injury has occurred, within 24 hours of the exposure having occurred the casualty should be taken to an eye hospital with full details of the type of laser in use at the time of exposure.

7.2.10 The planning should include the designation of one or more persons to be the laser safety officer (LSO). The LSO should have sufficient skills to recognize and manage the risks associated with the laser display. The role of the LSO is additional to that of the responsible person, who is in charge of installing or operating the laser effects. It is possible that some installations will require the additional skills of a laser protection adviser (LPA).

7.2.11 Provision should be made so that there is a sufficient number of people available during laser operation to monitor the laser effects' safe operation. Extra care should be taken for laser installations with large numbers of devices or complex projection configurations to ensure there are enough laser effect operators and laser spotters present during the installation and operation phases. In situations where people are required to act as observers (spotters) to ensure the safe operation of the effect (such as when using lasers outdoors and projecting into navigable airspace), sufficient designated spotters should be employed so as to have a clear view of the display area, with the sole task of monitoring the laser effect operation, and preventing any hazardous occurrences.

7.2.12 Notification to national or local health and safety authorities of the laser display or show can be required and, if so required, should be made as early as possible during the planning stage. Some authorities may also have licensing requirements or require notification not later than a specified number of days prior to a show. Notification may be required to include such information as locations, dates, set-up times, names and telephone numbers of responsible persons for both the show and the venue, number and operational specifications of lasers to be used and the types and sequence of visual effects to be employed.

Notifications should also be made, as appropriate, to

– aviation authorities for projections into navigable airspace,
– maritime authorities for projections into navigable waterways or harbours, and
– other relevant authorities for projections over rivers, lakes, shore or waterfront locations.

Notification to local aviation control authorities of planned projections into navigable airspace can also require the inclusion of geographical coordinates of the location and the azimuths and elevations of the planned projections. Specific international guidance is published by the International Civil Aviation Organization [3].

7.3 Set-up and alignment

7.3.1 Ample time should be provided for set-up and alignment. The amount of time required, among other things, should consider the number of laser projectors being used, their placement, and the complexity of the effects they are creating. The time required should be factored into the build phase of an installation; in particular, the alignment tasks, and verification of any exposure levels.

7.3.2 The area should be cleared of unnecessary personnel. The laser provider should liaise with the venue management prior to setting up, and establish a process of communications that will be adopted prior to turning on the laser projectors. The laser provider will normally inform the venue immediately prior to laser beams being emitted.

7.3.3 Locations where the exposure levels from laser beams may exceed the MPE should be posted with appropriate warning signs and barriers erected to restrict entry, prior to emitting any laser beams.

7.3.4 Alignments should be made at the lowest possible emission levels. However, it should be recognized that the ambient light level will critically influence the lowest possible emission levels for alignment work if this is being carried out by eye. A check should also be made at full operating power at the conclusion of the alignment to identify any spurious beams so that corrective action can be taken.

7.3.5 During alignment, access should always be maintained to the control system and its emergency stop control, so that the laser output can be quickly turned off if something unexpected happens. Often two people are required in order for this to be the case: one making the adjustments at the laser projector, and the other at the control system.

7.3.6 During set-up and alignment when laser beams can be projected in other than their final intended directions, temporary and permanent laser controlled areas should be established and warning notices posted in accordance with IEC TR 60825-14.

7.3.7 Checks should be made of controls including the correct placement and effectiveness of aperture masking and emergency stop controls. Checks should also be made that warning signs and barriers are in place as appropriate. Checks should be made that all components are securely mounted and locked into position. If scan-fail safeguards are used, the correct operation of such systems should be verified.

7.3.8 A record of the checks should be documented and kept.

7.3.9 Equipment should be secured and protected against misalignment or maladjustment between alignment completion and the performance. Installation of the equipment in a secured projection booth or the employment of security personnel can be necessary.

7.3.10 For laser installations where multiple performances take place over a period of time, regular checks should be carried out between performances to ensure the projection area alignment remains consistent, and safety controls are in place and operational. A record of these checks having taken place should be kept, and reviewed.

7.3.11 Coordination with safety and security personnel should be established and agreement developed of action to be taken for notifying the operator in the event of an emergency. Spectators should not be presumed to be cooperative with laser safety procedures or to be aware of proper procedures to follow to protect themselves from exposure or to avoid exposing others to hazards. Spectators should not be permitted to bring items, such as reflective balloons, flags, or phones on "selfie sticks", into the show site if overhead beam projections are to be used.

7.3.12 If the laser display installation makes any part of the venue accessible to laser effects in excess of the relevant MPE for the people expected to be present in that zone, the installer should communicate where these areas are, and what the exposure risk is, ensuring that the appropriate management are aware so that sufficient controls can be employed to prevent personnel being exposed to laser beams in excess of the MPE. A record of what risks have been identified, the controls that have been agreed, and between whom, should be kept.

7.3.13 The operator should have copies of any official clearances, records of alignment and operational or pre-show checks, and operating instructions in his or her possession at the show site.

7.4 Operation

7.4.1 If the display or show is evaluated by a local jurisdiction or aviation control authority, the operator should resolve any concerns prior to beginning the laser display or show. Aviation control authorities can frequently require the operators of outdoor laser displays or shows to employ observers with the ability to directly terminate the emission through an override mechanism, or to warn the projector operator of approaching aircraft. People designated as observers (spotters) should be able to carry out this task without other distractions when the laser effect is in use.

7.4.2 Prior to beginning high power operations, the operator should, if at all possible, perform a final low power alignment check to assure that components have not moved since completion of the set-up. An auditable record of this check should be maintained.

7.4.3 The operator should make certain that there is visual control of all projections during the laser display or show. It is acceptable to employ observers who are in immediate communication with the operator if the operator cannot maintain personal visual control.

7.4.4 The operator should be prepared to immediately terminate any projections that create a hazard as a result of any emergency such as unruly behaviour of the spectators. An emergency is considered to be any situation that can result in possible exposure of spectators, performers, operators or others to laser beam exposure levels in excess of the limits specified in 5.2, 5.3 or 5.4.

7.4.5 In the event of an emergency shut down the laser should not be used again until it is understood what went wrong, and controls have been reviewed and updated to reduce the likelihood of reoccurrence. If an incident of excess exposure is suspected, the appropriate contingency plan should be carried out, where medical attention should be sought. Vision can initially be checked, using an Amsler grid test.

7.4.6 The operator and venue should record how the event proceeded, noting successful operation, or if there were any difficulties or incidents encountered during the performance. It is beneficial to create the record at the time of the event, which can additionally be used to review and improve the safety management on future laser display projects.

7.5 Display safety record (DSR)

The laser safety officer (LSO) should maintain at the show site a display safety record (DSR) containing full and detailed information on how laser safety is managed. The DSR for each laser display or show should be kept up to date at all stages of implementation (i.e. initial design, planning, installation, alignment, operation, maintenance, servicing, modification and dismantling).

National requirements can be more specific, but the DSR should include:

a) details of the laser display or show, including equipment, location, layout of the venue, type of laser effects and beam paths in relation to spectators, ancillary personnel and performers;

b) characteristic of the laser beams, including maximum beam power, wavelength, divergence, maximum and minimum scan rates, and scan-fail safeguard fault conditions and response time;

c) all relevant safety information relating to all stages of implementation of the laser display or show;

d) the conclusions from the risk assessments for all stages of implementation of the laser display or show;

e) control measures in place and the rationale for them;

f) the names and contact details of designers, installers, modifiers, operators, LSO and owner of the laser display equipment;

g) contingency plans;

h) any operation and display approvals and restrictions issued by regulatory authorities (both local and national);

i) relevant details from the laser equipment manuals conforming to 6.1 and 6.2 of IEC 60825-1:2014;

j) for laser displays where audience illumination is intended, a record of the selected spectator MPE, exposure level measurements, and details of measurement instrument and configuration;

k) for laser display effects reliant on a scan-fail safeguard to achieve exposure within the MPE, performance criteria and operational tests conducted.

7.6 Contingency planning

7.6.1 General

Where Class 3B or Class 4 lasers are used, or where the potential for accidental exposure to laser radiation in excess of the MPE exists, contingency plans should be prepared. The contingency plans should consider three scenarios:

a) an actual eye injury;

b) an actual skin injury (for Class 4 lasers only); and

c) an exposure in excess of the MPE that had the potential to cause an eye injury.

In the event of an actual or suspected hazardous exposure to laser radiation or other laser hazard (an accident), or a possible failure of a protective measure which could have led to an accident (an incident), laser emission should be terminated immediately.

7.6.2 Dealing with an actual eye injury

A plan should be in place to manage a person who has an eye injury following exposure to laser radiation. Factors to be considered include the following.

a) Immediate first aid action should be taken, which can include calling for medical assistance. Unless advised otherwise, the injured person should be seated.

b) It is generally appropriate to treat the incident as a medical emergency and immediate action should be taken to get the injured person to an appropriate medical facility – usually an accident and emergency hospital due to the risk of shock.

c) Basic information about the laser beam should accompany the injured person to the hospital. Such information should include the part of the eye most likely to be at risk from the wavelengths of the laser beams in use at the time.

d) The plan should be recorded, be easily available and rehearsed at appropriate periods. It can be appropriate to develop a pack of information that can be easily grabbed and taken with the injured person.

7.6.3 Dealing with an actual skin injury

Apart from chronic exposure to ultraviolet radiation, which can result in lesions developing over time, the most likely skin injury from a laser beam will be a thermal burn. This should be treated in the same manner as a burn caused by a flame or exposure to a hot surface or substance. Medical advice should be sought on whether attendance at a hospital is required, based on the depth and area of the burn.

7.6.4 Dealing with a suspected eye injury

If there is no obvious eye trauma or the risk assessment suggested that eye exposures to laser radiation in excess of the MPE were unlikely, then any suspected incident is unlikely to be an emergency. If the laser beam had the potential to be a retinal hazard (400 nm to 1 400 nm) then it can be appropriate to undertake a quick test of visual function by either using an Amsler grid or asking the individual to read some small text.

7.7 Incident reporting and accident investigation

Any incident should be reported to the management of the organization providing the laser effects, and the facility where the incident occurred.

NOTE Legislation in some countries requires the reporting of occupational incidents and accidents to the appropriate regulator.

In all cases where a hazardous exposure is suspected, a full investigation to ascertain the circumstances surrounding the event and the likely magnitude of the exposure should be undertaken, and the conclusions of this investigation documented. In the case of an incident, the reason for the possible failure should be determined, and any necessary changes to the system of protective controls should be introduced before re-use of the laser.

8 Laser display risk management

8.1 Laser effect exposure risk

The inherent variety of laser effect types used in laser displays, and the range of locations in which a display can be performed lead to a wide range of risk factors that can influence the overall exposure risk in executing a particular laser display. Risk assessment should be used to identify specific hazards and decide upon suitable controls to reduce risk. The complexity of a laser display installation will have some bearing on risk, with shows that incorporate large numbers of laser projectors, or that rely on moving sets, resulting in more factors to manage than show applications with a single device in a stable location with the beams non-accessible.

In general terms the exposure potential, and hence risk, of any laser effect at performance time can be considered as falling into one of three broad categories as summarized in Table 2. By evaluating any laser effect or show under these categories, the complexities in using a particular laser effect can be quickly appreciated and indicate where most effort to prevent exposure should be concentrated.

Table 2 – Laser effect category

Non-accessible effect	Potentially accessible effect	Intentionally accessible effect
No beams accessible	Beams in excess of the relevant MPE accessible, but no intended exposure	Intentional exposure of performers, spectators or both
Laser projector location, its stability, and separation distances, and means of achieving these, ensure laser beams are not normally accessible to spectators, performers or ancillary staff. Engineering controls should include barriers where necessary, and physical masking to prevent a fault directing laser beams outside of the intended projection area.	Laser projector location makes beam paths accessible to performers or ancillary staff. Normally requires a laser controlled area to be established. Controls are required to prevent accidental exposure. Engineering controls such as proximity sensors to control emissions are normally preferred over procedural controls such as instruction and warning to workers, which can be ignored or forgotten. Additional care is required to manage accessible laser effects during installation.	Audience illumination type effects. May also be used to illuminate a performer. Requires evaluation against the relevant MPE. Verification of the exposure levels used to create the laser effect should be carried out. If the exposure is reliant upon a scan-fail safeguard to ensure the MPE is complied with, the installation requires an evaluation of how effective and robust the scan-fail safeguard is. May require a laser controlled area to be established.

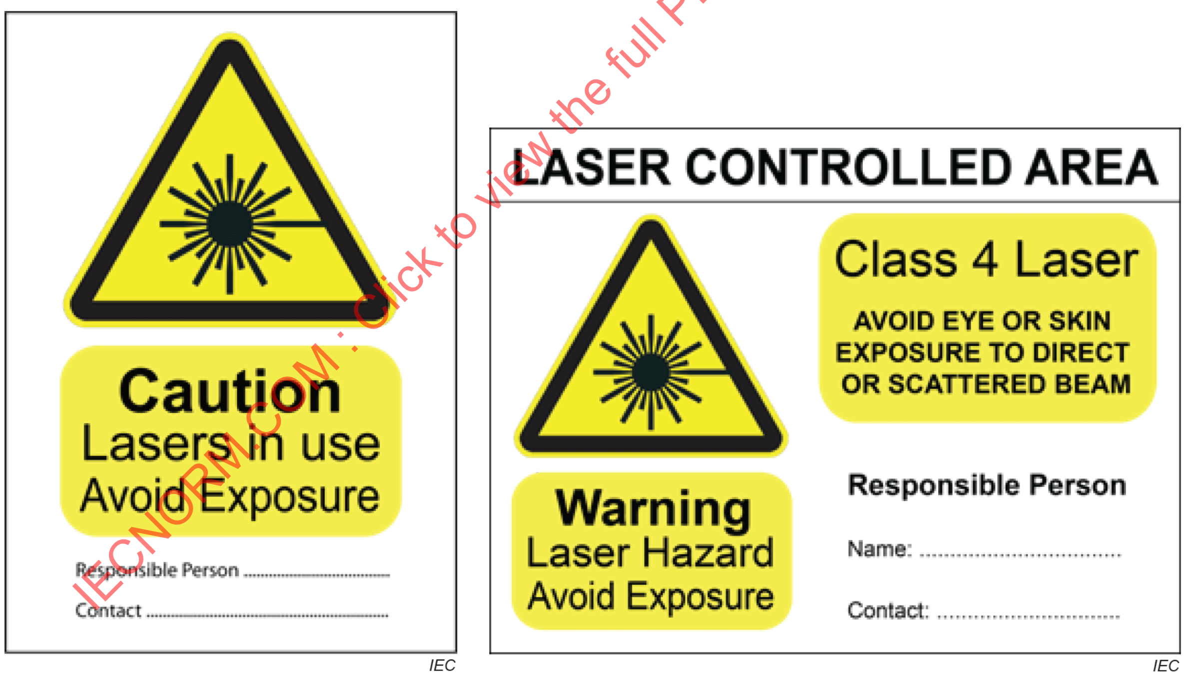
8.2 Laser display risk factors and controls

8.2.1 There are distinct phases during the implementation of a laser display project: design, install and build, projection area alignment, and operation (rehearsal and performance). In each of the phases where laser beams are emitted, an assessment outcome should decide the likelihood of people being present, in or near accessible beams that are in excess of the relevant MPE. If an exposure risk exists, then precautions should be taken to keep people away from the beam paths. If it is not possible to use the lasers when the area is completely clear of people, the area should be designated a laser controlled area. It should be expected that the areas that should be designated laser controlled areas can change throughout the lifecycle of the laser display implementation. Likewise, areas occupied by people can change from installation, through rehearsal time, and performance, so should also be considered.

8.2.2 Laser controlled areas should be designated, identified, and enforced ahead of the beam or laser effect alignment taking place.

8.2.3 The alignment should take place when the fewest people are working in the vicinity. Examples of how this can be achieved are through planning with the venue management staff, who can take steps to temporarily reduce the number of people working in an area, temporarily restricting access, or by planning the build with the production management to enable undertaking the alignment for when production crew are taking a rest break, for example.

8.2.4 Warning signage about laser use should be placed near to the laser projectors or accessible effects, in a prominent position where it will be seen by workers. The signage should consist of the standard laser warning symbol (ISO 7010-W004:2011-05), with a warning. Even if the laser effects will not normally be accessible it is useful to signal caution of the presence of laser devices, in case of people working at height, or a catastrophic failure, such as projector movement, where the beams could become accessible. An example is shown in Figure 6a. When a laser controlled area is required, the area should be clearly identified by signage (Figure 6b), warning that the area exists. Additional mandatory or prohibition signs can also be necessary, for example to help restrict access. Safety signs should comply with the requirements of ISO 3864-1 [4] in terms of colours, layout and dimensions and ISO 7010 [5] in terms of symbols. National requirements relating to signage specification and use exist in many regions. The signage should include the name and contact details of the responsible person on site. The signs should not be relied upon in their own right as a suitable means of control. The meaning, importance, and implications of the signs should be explained to workers that may be affected by their presence. This could be carried out during the general site induction held for workers.



a) b)

Figure 6 – Laser hazard warning signage

8.2.5 Venue operators can notify members of the public in the spectator zone about laser effects use in a similar manner to that when strobe lighting, pyrotechnics, and smoke or fog effects are used, either through an announcement, or a notice at the entrance.

8.2.6 Laser controlled areas are useful for identifying hazardous areas, but there are challenges in a production environment where most staff and crew members will have accreditation rights permitting them full access to normally restricted parts in the venue. Ensuring that people respect the laser controlled area is helped by making sure all workers are aware of the purpose of the laser controlled area, and what the risk is in entering it. Information about the exposure risk potential needs to be imparted to any worker who is required to carry out tasks in or near the laser controlled area. It is useful to maintain a written record of this communication having taken place.

8.2.7 Checklists can be useful for both the installer and venue operator alike for verifying and recording that common tasks and safety precautions have been put in place and executed. However, there is a risk that becoming too reliant upon a checklists could lead to the less regularly occurring issues being overlooked.

8.2.8 It is beneficial for venue operators to prepare a set of expectations of laser display suppliers ahead of the supplier coming to the venue. This could highlight installation issues specific to the site, which helps the laser supplier plan and accommodate them. The supplier can additionally learn what is required of them when they undertake work at the venue, and what protocol exists for informing the venue ahead of the laser being turned on and beam(s) emitted.

9 Exposure assessment

9.1 Recommendation

Exposure assessment should be carried out whenever laser effects are being used to illuminate people. The assessment is necessary so that any exposure meets the relevant MPE for the three different groups of people as described in 5.2, 5.3, and 5.4. In many countries there are legal obligations to ensure the MPE is not exceeded.

9.2 Guidance

The following is not a full guide to evaluating laser effect exposure but instead provides an overview of the process, highlighting common difficulties and approaches to conducting successful exposure evaluations. Those assessing and quantifying laser effect exposure should have a good knowledge of optical radiation and laser measurement principles, and an understanding of the relevant topics covered in IEC TR 60825-13 [6] and IEC TR 60825-14 [7].

9.3 Difficulties

9.3.1 Laser effects are produced primarily through movement and modulation of the source beam or beams. This is intentional in order to create a varied range of effects. The way in which the beam is modified through scanning and modulation might not be immediately obvious. However, it is important that early on in the assessment process a good understanding of these characteristics is obtained. If the nature of the beam being measured is not known, or is misunderstood, mistakes in the measurement process, more likely than not, lead to an underestimate of the hazard present.

9.3.2 Laser effects often modulate or scan a beam, meaning that the actual exposure is received as a short pulse or a pulse train of energy as the beam passes across the eye, or in the case of assessment, a measurement detector. This is known as the effective pulse duration (Figure 7). The majority of commercially available standard laser power meters are not appropriate to directly measure scanning or modulating laser effects, because they are unable to resolve what may typically be a pulse of energy that is a few tens of micro-seconds in duration. It is therefore important any instrument used for measurement has the appropriate bandwidth to resolve the pulse created by a scanning laser beam.

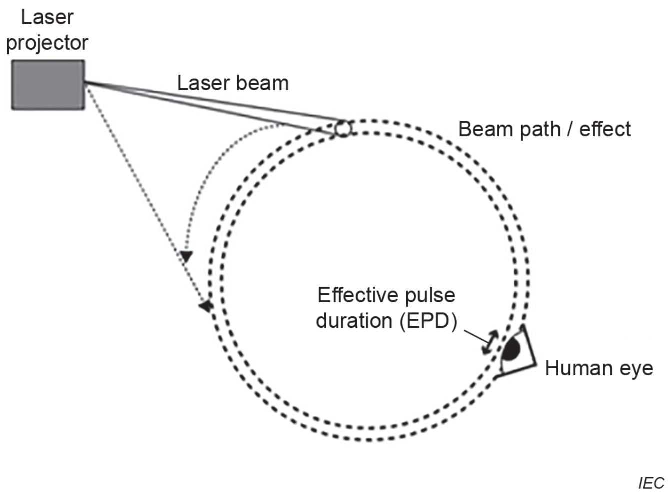


Figure 7 – Effective pulse duration

9.3.3 The nature of scanned laser effects leads to short pulses of optical energy being received by a laser measurement detector (Figure 7). Depending upon the type of detector and the sampling electronics of the measuring system, the measurement instrument might or might not be able to resolve the peak power created by the maximum amplitude of the energy pulses. For any scanning laser effect, the peak power will be a higher value than the average power, which is a function of peak power over time (Figure 8). The majority of commercial standard laser power meters are only capable of measuring and reporting the average power. For the exposure hazard assessment of scanned laser effects, standard laser power meters are not a suitable instrument to use for taking direct scanning measurements, because to correctly assess the exposure level the "peak" power should be known.

NOTE Irradiance can be determined from a power reading knowing the area of the detector.

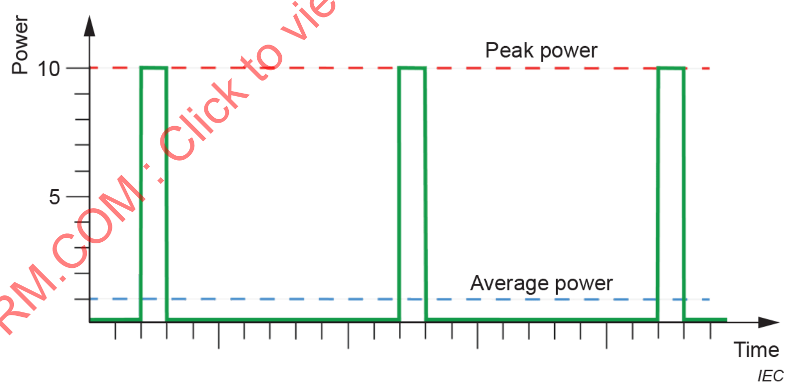


Figure 8 – Apparent pulse train at the measurement device highlighting the differences between measurement results for average power as measured by a standard power meter and peak power as measured by a specialized meter

9.3.4 Some laser projectors, including those that do not create scanned effects, vary the beam intensity by altering the duty cycle of the laser beam output, rather than reducing the continuous drive current to the laser. The variation in duty cycle – using pulse width modulation (PWM) – creates the appearance of altering the brightness of the laser effect. As a laser effect looks less bright there is a reduction in the average irradiance, but the higher peak irradiance remains, which can still present a hazard. Using a standard laser power meter to measure a laser effect that has had its brightness reduced in this fashion leads to the same difficulties (9.3.3) as measuring scanning laser effects.